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**Developing a Conceptual Framework for the Field
Failure Feedback Process from Service-to-Design**

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**Developing a Conceptual Framework for the Field
Failure Feedback Process from Service-to-Design**

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degree of Doctor of Philosophy

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ABSTRACT

This thesis addresses the product field failure feedback process from service-to-design, for the purposes of product enhancement within the heating technology manufacturing industry. The research provides insights into existing problems with processing field failure data as an aid to service, design and quality practitioners in their functional roles to support product performance, quality and reliability improvements. Extant research on field feedback process have examined field feedback as a fragmented process and focused mainly on improving the speed and quality of the information flow within. This study investigates such feedback as a holistic process and concentrates on operationalising and improving the feedback between service and design.

Understanding what is pleasing and dissatisfying for customers is critical for success in today's competitive market environment. Thus, this requires a systematic process for obtaining feedback from the field about product-in-use performance to influence the design of future product and service market offerings that will genuinely contribute to increased customer satisfaction. The feedback of product-in-use performance data can be used by design engineers to identify potential product failures and prioritise reliability issues, and so prevent their reoccurrence. Furthermore, product innovation and development processes are increasingly driven by shorter time to market, increasing product complexity, and increasing customer demands, all of which have contributed to the challenges of improving feedback from the service to the design. Such challenges need to be addressed if firms wish to actively pursue sustainable product innovation and develop genuine levels of organizational learning.

An in-depth case study was conducted with a sponsoring company and qualitative and qualitative data was collected through interviews, and questionnaire surveys. The results from the literature reviews and empirical work have been amalgamated to develop a conceptual framework for the effective field failure feedback process from service-to-design. The framework articulates the various stages of the feedback process and the operational conditions that privilege its effective management and organisation. This framework was subsequently validated with industrial experts using case study methods, following which refinements were incorporated into its overall design.

DEDICATION

This thesis is dedicated to my son
Hussein Mofopeoluwa Joshua Nasser

16/11/ 2008 -24/12/2008

*Why did you have to go so soon?
Now all I see are pictures of you,
I'll never get to hold you in my arms again
I'll never get to see the funny pictures you drew for me
I'll never get to see all the special things you could have done
Your sudden death has left a hole in my heart,
I will never forget the special moment we
shared together.
The memories will forever linger in my mind
It will be cherished forever till we meet again
If I could turn back the hand of time, you will be here to stay with me
I miss you so much"*

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GLOSSARY OF TERMS

CPI	Continuous Product Improvement
EDI	Electronic Data Interchange
EPSRC	Engineering and Physical Science research Council
FMEA	Failure Mode and Effect Analysis
IP	Innovation Process
MOPMIS	Month in Production, Month in Service
NPD	New Product Development
R & D	Research and Development
BERR	Business Enterprise and Regulatory Reform
MOPMIS	Month of Production Month in Service
DTI	Depart of Trade and Industry
EEF	Engineering Employers Federation
FFD	Field Failure data

CHAPTER 1: INTRODUCTION

This chapter outlines the background to the research, gives an overview of its focus and highlights its relevance to the current body of academic knowledge. In addition, it outlines the research aim and objectives and, the overall research approach undertaken to conduct the investigation. Finally, it illustrates the structure of the thesis and presents a brief abstract on each of the subsequent chapters.

1.1 Manufacturing industry

Manufacturing is defined by BERR (2008) as a sequence of functions, covering research and development (R&D), design, supply management, production, distribution, logistics and sometimes the provision of after-sales services. In the last few years there have been some major improvements across the manufacturing industry as companies take advantage of the growth and demand of the global market. Manufacturing is important to the economic growth and development of the UK and has been a major driver of innovation through the introduction of new products and associated services. Globalisation is making the manufacturing environment more competitive and providing opportunities for trade and investment which are becoming increasingly complex. The growth of emerging low cost economies such as China and India are posing both threats and opportunities to UK manufacturers. The ability to respond to this increasing competition and opportunities in emerging economies requires the capability of manufacturers to offer their customers innovative goods and services. If companies are to continue to succeed, R&D must be an ongoing activity that enables the company to compete effectively, and move towards becoming a market leader. According to the report on manufacturing strategy, written by the former Department of Trade and Industry, innovation is crucial to the future of the UK manufacturing industry (BERR, 2008).

Manufacturing industry is also experiencing a shift from the production and sales of products towards the provision of services based on the functionality of a product. A number of authors argued that in most cases, consumers of a product do not demand for the product as a physical object but seeks the utility and function provided by the product. This concept is known as product service systems (PSS). Product service systems are defined in the literature as *"a marketable set of products and services capable of jointly fulfilling a user's needs"* (Mont, 2002). This involves changing the business focus of attention from producing and selling only physical products, to selling a combination of products and services which are jointly capable of fulfilling specific client demands. The product to service shift and introduction of Product-Service Systems (PSS) are extensively discussed in the literature and Baines *et al.*, (2007) present a state-of-the-art literature review of the field. The shift to PSS is motivated by the challenges faced by manufacturing industries and the recognition that the combination of product and services is a new path towards profits and growth (Bates *et al.*, 2003). Benefits of product service systems for manufacturing companies are numerous and includes the following: better feedback on consumers needs which helps improve the relationship with consumers, provides opportunities for the creation of service innovations, identifies new market trends and

development, improves operational efficiencies financial growth and adds value to products (Mont ,2002)

1.1.1 Domestic heating manufacturing industry

The heating, ventilation and air-conditioning (HVAC) market is influenced by building regulations, environmental regulations and EU guidelines on emissions (Key Note database). These regulations have influenced the development of the industry as many manufacturers and suppliers constantly assess and improve the efficiency of their systems. Growth in this industrial sector could have been achieved through acquisition. Therefore traditional UK suppliers such as Hepworth and Potterton were acquired by larger companies such as Vaillant Group.

In the same way as other manufacturing industries, the HVAC industry is also affected by the increase in the importation of products from emerging low cost countries. However, the UK market for boilers has seen a major increase in the last few years, with annual sales rates peaking at 29% in 2005 (Mintel Report, 2008). The main contributor to the increase in sales has been, changing legislation, government policy that requires more efficient 'greener' boilers which are more advanced in value, together with a booming housing market and a strong consumer market (Key Note Report, 2008).

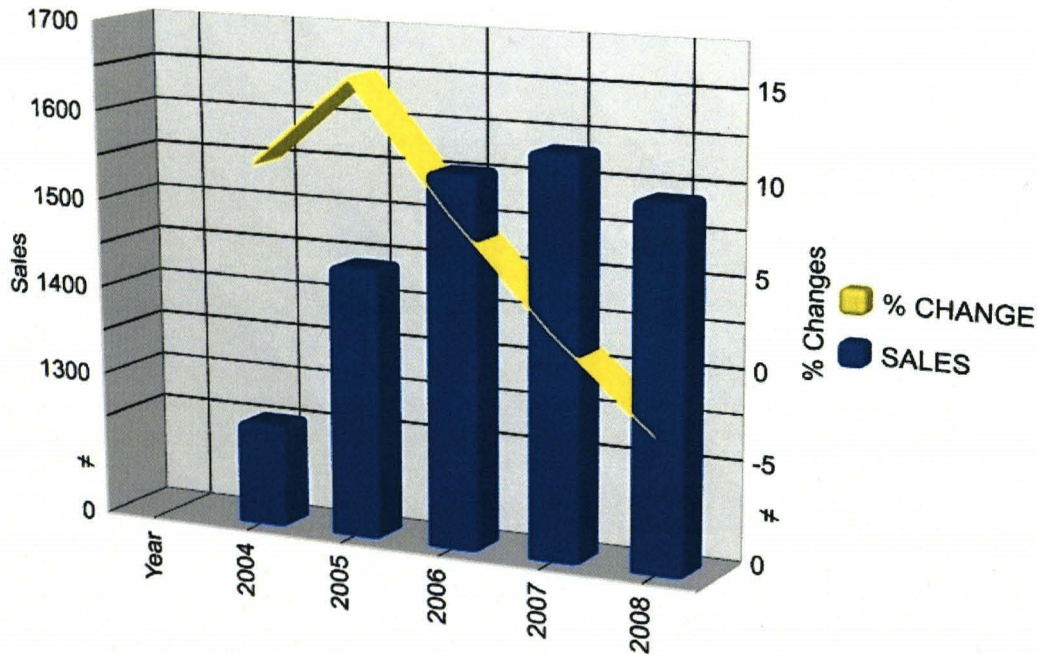
According to the new regulations, Building Regulations Part L1 which was introduced in March 2006, boilers have to meet new energy efficiency standards. This means that all boilers are now required to meet SEDBUK (Seasonal Efficiency of Domestic Boilers in the UK) 'A' (efficiency of more than 90%) or 'B' (efficiency of 84% to 90%) ratings, as part of Government plans to reduce UK carbon footprint levels. The SEDBUK label in boilers is equal to the energy label found on domestic appliances, such as washing machines, fridges and dishwashers, and has lettered ratings from A to G. The rating represents the average annual efficiency achieved in typical domestic conditions, making reasonable assumptions about how it's used the climate, controls, and other influences.

The impact on manufacturers has been the need for more detailed specifications about new heating products in new house building programmes (Mintel Report, 2008; Key Note Report, 2008). The UK domestic central heating market is dependent on replacement sales, which account for approximately 65% of total sales. This is influenced by consumer spending, as the replacement of a boiler or a complete system tends to be purchased only when needed. Table 1-1 below presents the chart of the UK domestic central heating market.

Table 1-1: The UK Domestic Central Heating Market, by Value, 2004-2008

Year	Sales	% Change
2004	1 252.5	+10%
2005	1 440.5	+15%
2006	1 553.2	+8%
2007	1 583.4	+2%
2008	1 540.2	-3%

The UK Domestic Central Heating Market, by Value, 2004-2008



Source: ONS Data and MBD estimates

MINTeL

Figure 1-1: Chart showing the UK Domestic Central Heating Market, by Value, 2004-2008

1.2 Background to research

Manufacturers need to expand their investment in innovation if they want to sustain a competitive advantage. Innovation might comprise a variety of activities such as product or service development, design, marketing, research and experimentation, and investment in new machinery or technology. A survey conducted by Engineering Employers Federation (2006) showed that 80% of companies using an innovative approach to product development reported improvements in profitability, productivity and responsiveness to the market. Product innovation and development processes are increasingly driven by a need for shorter time to market, increasing product complexity, and increasing customer demands.

These challenging business drivers demand the need for effective feedback regarding **products in use** and **failure in the field** for product improvement. Field feedback provides insights into product performance in addition to the customers' experience of the product quality. Consequently, manufacturers are collecting and analysing the field data from such feedback in order to boost the quality and reliability of their products and ultimately improve customer satisfaction (Karim and Suzuki, 2005). This information can be used by design engineers to identify future potential failures in products and so prioritise major reliability issues and mitigating actions in the product development process. Such challenges need to be addressed if firms wish to actively pursue product innovation and development through genuine levels of organisational learning. Improving feedback requires systemic changes with the potential to make incremental changes to existing products and services or to radically replace them with something completely new (Goffin and Mitchell, 2005).

As manufacturing organisations move towards providing improved products and services, the efficiency and effectiveness of the field failure feedback process from service-to-design, becomes more important for product quality and reliability improvement. This could help an organisation improve their market share with continuously increasing profits. The launch of a product into the market is not the end of the product development cycle. Increasingly it is the beginning of another product lifecycle which includes service, maintenance, repair and continuous improvement. Thus, problems that occur in the product in use could be prevented, or the impact could be minimised through the effective application of early feedback and rapid response from service into the product development process, ultimately to improve the product quality and reliability and overall value in use.

A product development project without effective feedback on the performance of the product in the field can result in the development of products that do not meet product specifications or customer expectations. Product failures may be related to any aspect, be it technology, people, systems, components or the process of manufacture. It is important that manufacturing organisations continuously improve their products and adapt their processes adequately to achieve sustained continuous improvement. In most organisations the task of improving product quality and reliability focuses on technical issues such as ensuring the functional specification of the product satisfies customer requirements. However, Ouden *et al.*, (2006) state that non-technical issues such as; how the product is used by the customer, the environment in which the products operate and the users expectation of the different product functions, all play an important role in improving product quality and reliability. An important implication of their research is that both technical and non-technical information about the product in use needs to be captured from the field.

A number of research projects conducted on product reliability improvement have emphasized the need for feedback processes (Busby, 1998, Petkova, *et al.*, 2005, Molenaar, *et al.*, 2002, Boersma, *et al.*, 2004, Tan, *et al.*, 2000). However, there is a dearth of research that focuses on how the practise of feedback from service-to-design is enacted. This research is concerned with an empirical exploration of the antecedents of an effective feedback process in one leading multinational manufacturer of heating products (boilers). The thesis draws together existing literature about product improvement to better understand the feedback process from service-to-design on 'product in use failures' for future enhancements in product development.

1.3 Problem statement

The heating system technology industry like any other manufacturing industry is faced with fierce competition. The pressures of shorter time to market, increased product complexity and stronger customer demands have contributed to the need for better integration between design and service functions. The organisation is challenged to meet increasing demands from their customers for quality products with reliable functionality that performs effectively over a period of time. Offering high quality products means that the manufacturers must have an understanding of how the customer gauges quality. This requires obtaining accurate information on existing product performance in the field to be fed back to design engineers, enabling improvements to be focused on obstacles to meeting customer requirements. The feedback of product in use failures is needed during the design process to influence the design of future product and service market offerings that will genuinely contribute to increased customer satisfaction.

Product in use performance data can be used by design engineers to identify potential product failures and prioritize reliability issues, and so prevent recurring errors in future market offerings (Ajayi and Smart, 2008). The early detection and analysis of product in use failures and failure modes enable the selection of appropriate actions to ensure the effective correction or elimination of future failures (Ajayi and Smart, 2008). The sooner a failure is detected, the less potential there is for damage, harm, or dissatisfaction to be inflicted on customers (Ajayi and Smart, 2008).

Indeed, in some cases, such detection activity is under the jurisdiction and control of regulatory bodies. Inevitably, with every new product development project there is a degree of risk and uncertainty involved regarding its market success. Hence, manufacturing organizations are faced with the problem of how to predict, evaluate, and improve the quality and reliability of their product before it reaches the customer.

Although product field failure data provides valuable information on product performance in the field, it is often limited in scope and details. This is because it only captures the brief fault descriptions generated by service engineers as articulated by the customer. Other data such as, the contextual information regarding the operating environment and nature of usage which may also have affected the performance of the product is not usually captured by service engineers. One of the issues of emerging concern relating to feedback is the level of detail about product failures that is communicated back to the product designers' and quality engineers.

Consequently the field failure information is often missing, incomplete, untimely and inaccurate. Another major limitation of the current industrial practises is the lack of integration between the field failure data and the system level failure mode and effect analysis (FMEA) process, amongst the backdrop of insufficient communications between service and design.

1.4 Research aim & objectives

1.4.1 Aim

To develop a conceptual framework for an effective field failure feedback process from service-to-design.

1.4.2 Objectives

In order to achieve the above mentioned aim, the following research objectives were set;

- To review extant literature and identify the salient issues associated with feedback from service-to-design in the context of product improvement.
- To empirically inform theoretical findings to develop a coherent conceptual framework for field failure feedback process from service-to-design.
- To further validate the framework via case studies

1.4.3 Research scope

The scope of this research will encompass a focus on the feedback process concerning product failures in the field to the conceptual design stage of product development. In doing so, it will support decision making regarding the prevention of failure or 'reoccurring' in current lines and a new generation of products. In line with the aim and objectives of the research, the scope of this research can be summarised as follows:

- Only the conceptual stage of design will be explored. This refers to the requirement generation, product specification and preliminary design stage.
- The design activities in this context include domestic electro-mechanical product and manufacturing process design.
- The process of information flow regarding product field failures between service and design.
- The research will concentrate primarily on field failure data and how it is used for the purpose of product improvement.
- Product innovation in this research context is concerned with the improvements of existing similar products and new product generation.

- Develop a conceptual framework that will guide practitioners in designing and developing an effective service-to-design feedback process concerning product in use or field failures.

Although the current study has been conducted in the heating appliance sector, the author believes that the generic findings could be applicable in other manufacturing sectors.

1.5 The research approach

The general approach used in this research is that of an exploratory case study. It involves the collection of qualitative and quantitative data from both academic literature and industrial investigation. A comprehensive literature review was conducted to support findings from the industrial practises. A case study approach using the interview technique was also adopted for the research validation process. The case study company is Vaillant Group, a European leading manufacturer of heating systems. The company design and produces tailor-made products, systems and services for domestic use. An exploratory approach was chosen because there is a dearth of literature focusing on the feedback of product field failure data from service-to-design for the purpose of product improvement. Existing research on field failure feedback process is limited to the need and importance for feedback. This research seeks to explore the antecedents of effective service-to-design feedback and embody a conceptual framework focused on the management and organisational issues. Subsequent investigations facilitated the validating and refining of the initial framework.

1.6 Thesis structure

The thesis structure is illustrated in figure 1-1 and contains the following main chapters:

Chapter 1: Introduction

Provides an overview of the research background, research focus, aim and objectives and describes the structure of the thesis.

Chapter 2: Literature review

This chapter provides a review of the literature on the feedback process of field failure data from service-to-design for the purpose of improving product quality and reliability and it argues the need for an effective feedback process. The literature includes several sections covering; new product development, FMEA, product quality and reliability improvement, field data and after-sales service support. Existing research in this subject area will also be reviewed to establish limitations and gaps in current research.

Chapter 3: Research aim and programme

The chapter discusses the methodology adopted in conducting this research to ensure that the aim and objectives are met.

Chapter 4: Findings from Empirical study

This chapter presents and discusses the methods and findings from the empirical studies to address the research issues. The aim is to identify the findings from the investigation that helps to fulfil the achievement of the research objectives.

Chapter 5: Development and discussion of conceptual framework of service-to-design feedback process

This chapter presents a discussion on the research findings in the context of existent literature and develops the conceptual feedback process framework from service-to-design for product improvement purpose.

Chapter 6: Validation of proposed framework

In this chapter the developed framework is validated in line with the findings from the case study conducted with industrial experts. Feedback from industrial experts highlighted areas of improvements and necessary modifications were made to the conceptual feedback process framework.

Chapter 7: Conclusions

This chapter presents the conclusion of the thesis. It showed how the research aims and objectives have been met. The contribution to knowledge made by this thesis is identified and it discusses the limitations and outline suggestions for future research.

1.7 Conclusion

This chapter has provided an overview of the research background and problem statement. It has outlined the aims and objectives of the research and provided an overview of the structure of the thesis. The references referred to in this thesis will be presented in alphabetical order on the reference page. The appendices of the thesis give details and examples that may provide further insight into understanding the thesis.

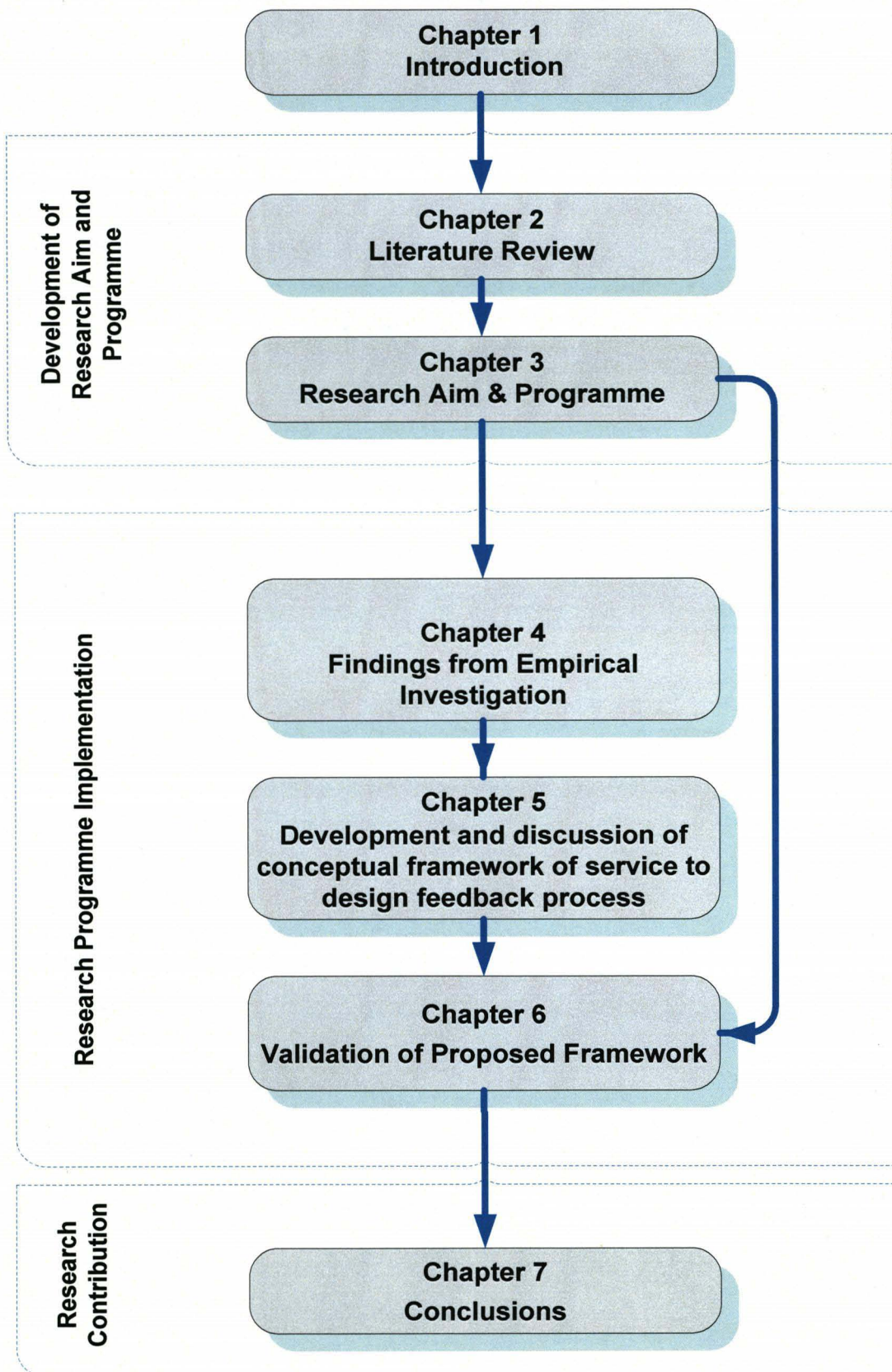


Figure 1-2: Thesis Structure

CHAPTER 2: LITERATURE REVIEW

The previous chapter has outlined the fundamental gap driving the need for this research. In this chapter, the purpose of the literature review is to study and provide an insight into the literary contributions in relation to the relevant disciplinary domains. More specifically to locate the novelty of this research and position the author's contribution to knowledge. The main aim of the chapter is to examine the service-to-design field feedback process for product improvement. A critical thematic and review of extant literature is presented. Finally, the key findings of the review process are summarised.

2.1 Definition of new product development

Understanding the context of new product development requires a definition of the subject matter in order to provide a basis for further literature review. The Product Development & Management Association (PDMA) handbook of product development provided the following definitions of a new product and the product development process:

A product is a system comprising several elements which can be broken down into an hierarchy of levels. Blischke and Murthy (2000) classified product into seven levels of hierarchy with 'system' at the highest level and 'parts' at the lowest level. The diagram in figure 2.1 illustrates the hierarchy of a product.

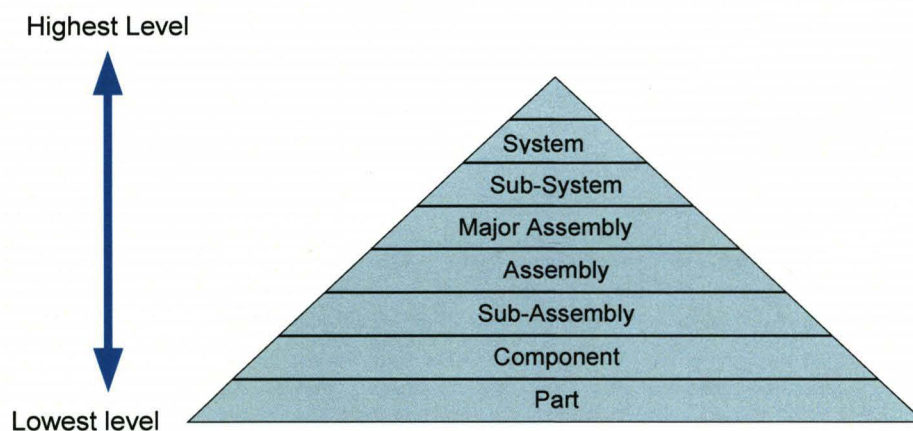


Figure 2-1: Hierarchy of a product

New product development (NPD): "The overall process of strategy, organization, concept generation, product and marketing plan creation and evaluation, and commercialization of a new product. Also frequently referred to as "product development" (PDMA, 2003, p595)

New product development process: is defined as "A disciplined and defined set of tasks and steps that describe the normal means by which a company repetitively converts emergent ideas into viable products or services" (PDMA,2003, p596)

2.2 New product development process (NPDP)

New product development is part of the innovation process (Roozenburg and Eekels, 1995) and is critical to the growth and success of many organisations. A number of research have focused on the success and failure of a new product (Ulrich and Eppinger, 2002; Cooper (2003) and identified factors that are fundamental to new product success. There are different types of new products (Cooper, 2001), for example, new to the world, new product lines, additions to existing product lines, improvements and revisions to existing products, repositioning and cost reductions (Booz Allen and Hamilton, 1982; Trott, 2005). Whatever the case, the underlying motive of product development is to gain the competitive edge. Over the years this has become the dominant driver of competition in many industries. As a result of the intense global competition, constant changes in technology and increasingly demanding customer needs and expectations, the product development process is becoming more complex and the outcome of the process is less certain (Keizer *et al.*, 2005).

According to Ulrich and Eppinger (2002) new product development process involves a set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product. Nanda (2005) described NPD as a gradual process of transformation of specified product requirements into a finished product. Cooper (2003) argued that it is a process by which an organization uses its resources and capabilities to create a new product or improve an existing one. Based on the various definition of product development process, it can be concluded that in general it is a process that transforms an idea and opportunity into a real product.

2.2.1 Stages of NPD

NPD is presented in various literatures as consisting of a varying number of steps, stages and activities (Cooper, 1993; Ulrich and Eppinger, 2002). Page (1993), argued that the variety of conceptions and compositions, together with the differences in terminology present difficulties when researching the NPD process. There are two approaches to the NPD process as identified by Nonaka and Takeuchi (1986). The traditional approach involves a sequential method where one phase of the process would have to be complete before the next phase can begin, the second approach is the overlapping approach which has no structured approach to the development process, instead it involves a multidisciplinary team who work together through the product development lifecycle. Tasks in different phases can be worked on in parallel, for example tasks in phase three can be started before tasks in phase two is completed (Nonaka and Takeuchi, 1986).

Traditionally NPD processes are managed through milestones and deliverables (Minderhoud, 1999). It involves parallel as well as sequential product development projects (Gieskes and Langenberg, 2001). The sequential NPD model is performed in various time based stages. The commonly used stage-gate approach splits the

NPD process into a series of sequential phases. Each gate, also known as milestones, must be completed before proceeding to the next phase. Milestones are used to achieve a certain level of quality in the NPD project. Although product development models have similar goals they have different stages (Cooper, 2001; Ulrich & Eppinger, 2002; Wheelwright & Clark, 1992). Table 2.1 shows a comparison of product development models. Rudder *et al.*, (2001) implied that an organization should not be attached to one particular product development model but consider the basic fundamentals of a model, adapt and amend it to their particular circumstances.

However, a stage gate approach to product development is widely implemented in many organisations for conducting a product development project. It is a conceptual and effective roadmap for moving a new-product project from idea to launch, Cooper (2001). The stage-gate approach is effective under certain conditions such as, when innovation time is shorter than the rate of change in business environment and also for controlling quality and reliability (Meyer, 1998). Stage-Gate divides the product development process into distinct stages separated by management decision gates. The purpose of the go/no go decision between each stage is to identify and reduce the risks. Figure 2.2 illustrates the stage-gate process model.

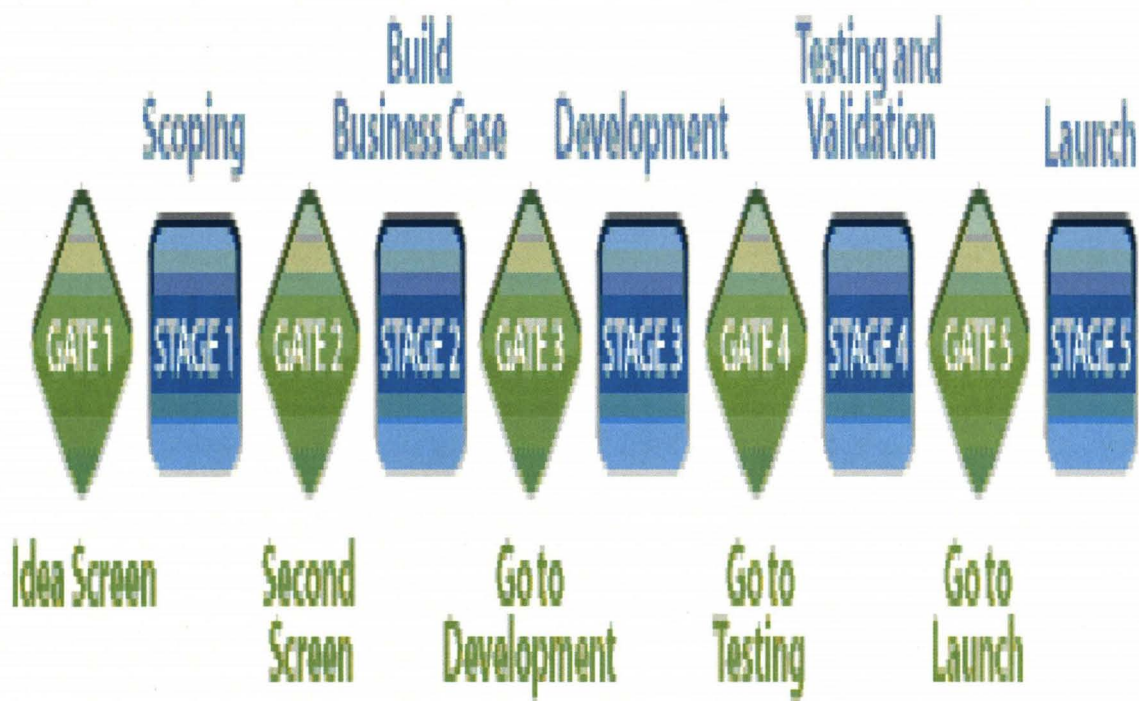


Figure 2-2: Stage gate product development model (Cooper, 2001)

Table 2-1: Comparison of stages in NPD

Steps in Product Development	Booz, Allen & Hamilton, 1985	Bingham & Quigley, 1989	Kotler & Armstrong, 1991	Graf & Saguy, 1991	Urban & Hauser, 1993	MacFie, 1994	Fuller, 1994	Ulrich & Eppinger, 2000	Cooper, 2003	Goffin & Mitchell, 2005
Opportunity Identification					x					
Exploration	x									
Planning								x		
Idea/concept (Generation)		x	x			x		x	x	x
Idea/concept (Screening)	x	x	x	x		x	x		x	x
Prioritising										x
Design					x			x		
Feasibility				x			x			
R&D										
Concept Development & Testing		x	x		x			x		
Marketing Testing Development			x							
Introduction					x					
Business Analysis	x	x	x						x	x
Product (Development)	x	x	x	x		x	x		x	x
Consumer trial							x			
(Testing) Marketing	x	x	x		x	x	x		x	
Packaging development						x				
First (production) run							x	x		
Production Ramp-up									x	
Life-Cycle Management					x					
Product Introduction		x								
Launch						x			x	x
Commercialization	x		x	x					x	x
Maintenance				x						

The shaded stages are commonly used in product development models. The stages are Idea/Concept Generation, Idea/Concept Screening, Concept Development and

Testing, Product Development, and testing; see (Ulrich & Eppinger, (2002) for details. All of the stages identified in table 2.1 are important for a successful product development project.

The product development process is performed as an interdisciplinary activity requiring contributions from all functions within an organisation. Traditionally, the NPD process has been characterised by functional division, particularly between Marketing, R&D and Production. Nowadays, NPD is seen as a vital cross-functional business process, which also involves external suppliers or partners collaborating together to achieve a successful product development (Mello, 2001). Using a cross functional team in new product development ensures diversity in knowledge ideas and a variety of information sources. Schilling and Hill (1998) asserted that the effective use of a cross-functional team in new product development lowers costs and reduces product defects. Fredericks (2005) stated that cross-functional input to product development is dependent on having a shared understanding of the tasks required at different phases of the NPD process. Team diversity in product development project provides people with different training, experience, perspectives and personalities which, when combined, is used to develop a creative product that satisfies customer needs (Ulrich and Eppinger, 2002). However, Berndes *et al.*, (1996) argues that product development organisation needs to think in a process oriented way, in order to establish an holistic view of the process, instead of thinking in a functional and departmental oriented way. Improvements to a product are made during the design process; therefore this thesis would examine the role of design in product development which would be discussed in the next section.

2.2.2 Roles of design in product development process

A design is described in technical drawings which contain data about the shape, dimensions and materials of the parts, the manufacturing techniques to be applied and the process of assembling the parts into a complete product. However, to design a product there is much more involved than just drawing. Design evolves over time through countless hours of research, analysis, engineering and prototyping, and finally testing, modifying, and re-testing until the design has been perfected (Clark and Wheelwright, 1993; Ulrich & Eppinger, 2002).

Design is a major determinant of quality, which plays a critical role in determining the success or failure of new products. It influences the performance, quality, cost, and development time of the product. Design process involves transforming the needs of a customer into a product that satisfies their needs. Through the acquisition of a better understanding of customers' needs and using the acquired knowledge to design better products and services, a customer orientation should have a direct impact on customer satisfaction (Nilsson *et al.*, 2001). The goal of design is to meet customers' requirements whilst considering the business pressures. However, gaps in the design process can lead to reliability problems. In order to minimise the gaps in the design process and ensure a good design, a structured approach is used during the design process (Clark and Wheelwright, 1993).

Booker (2003) identified the consequences of a design fault being the loss of reputation and sales, costly modifications, product recalls and bankruptcy. However, the more problems which can be prevented earlier on in the development process,

the fewer problems that have to be corrected at a later stage when it is costly to make changes. According to Arunajadai *et al.*, (2004) the recognition of potential failure modes during the product design process is vital for creating failure-free designs. Pahl and Beitz (1996) divided the design process into four phases which include product planning, conceptual design, embodiment design and detail design. According to Suh (1990), the role of a product designer consists of defining customer requirements, conducting a functional analysis to produce the design concepts, and then link the produced concepts to components and sub-systems.

As the complexity of a product increases, it has become more difficult for designers to comprehend all possible implications of component failures on a design (Price and Taylor, 2002). Crosby (1979) traced most product quality problems to poor design. This may be attributed to the fact that knowledge about product functionality in the conceptual design phase is hard to capture and is often spread across technical field (Kitamura *et al.*, 2004). Conceptual design is considered as the most important phase of the design process because the decisions made at the conceptual stage have an impact on all subsequent phases of the design process (Roozenburg and Eekels, 1995). Therefore, design engineers are faced with the challenge of making crucial decisions at the conceptual stage when choosing the most likely modes of failure. This decision can be costly if the wrong decision is taken.

Product design affects other people's work and one way of realising this is through service engineers' complaints on product failure in the field. Encouraging design engineers to consider how their design operates in the field, and more importantly how they fail, is crucial to achieving reliable designs (James *et al.*, 2002). Engelhardt (2000) emphasised that a major difficulties faced by designers is establishing the relationships between various design parameters and their effect on a product's functional requirements. As a result, unforeseen failures may be built into the product. The occurrences of failure modes in products are often due to the complex interactions between various design parameters and process variables which were not anticipated during the design stage (Manner *et al.*, 2006). Thus, the prevention of field failures during design and their detection in manufacturing becomes a challenge (Manner *et al.*, 2006). If design engineers have access to information on product failures from the field they are able to make changes on the product to avoid potential failures.

2.2.3 The Design Process

A number design process models are presented in the literature (Pugh, 1991; Hubka & Eder, 1992; Roozenburgh & Eekels, 1995; Pahl & Beitz, 1996; and Ulrich & Eppinger, 2002). The design of a new product consists of the following stages which are; design brief, design specification, concept design, detail design, manufacturing and testing and sales. The design process are categorised into different phases, which have been given a variety of names by different authors. Pahl and Beitz (1996) split design into four phases which include product planning, conceptual design, embodiment design and detail design. Baxter (1995) used four phases similar to Pahl and Beitz (1996) but without clear distinction between embodiment and detail design. Ulrich and Eppinger (2002) included product planning and conceptual design into the same phase, but maintained the other two phases. Hsu and Woon (1998) divided a design process into three phases, i.e. product design specification, conceptual design and detail or final design. In general, the design

process consists of mainly four phases as described by Pahl & Beitz (1996). They are:

- *Planning and Clarification of the task:* This should establish a product idea that is required in the market. Ulrich and Eppinger (2002) argue that this proposal must be technically viable, identify customer needs and take them into consideration.
- *Conceptual design:* Ullman (1997, p. 120) defines a concept as "*an idea that is sufficiently developed to evaluate the physical principles that govern its behavior.*" During this phase, the form, function and features of a product (Ulrich & Eppinger, 2002), essential problems are identified and evaluated in order to generate solutions.
- *Embodiment design:* describes the assemblies, components and parts, as well as their geometrical shape, dimensions and materials. Preliminary layouts are established, (Roozenburg & Eekels, 1995). A number of embodiment designs are often required before a definite design can emerge (Pahl & Beitz, 1996).
- *Detail design:* involves the design of the sub-systems and components that together make up the whole design (Pugh, 1991). The outcome of the Detail Design phase is a specification of what is to be produced. Such as specification of dimensions, materials and tolerances of all the parts in the product.

2.3 Challenges in New Product Development

Organisations are faced with a number of challenges when performing new product development process, and many of these challenges have been focused upon in product development literature. Some of the dominant driving forces of today's competitive business environment are technological advances and increasing customer expectations. As a result products are becoming more complex whilst product life cycles are getting shorter. Existing literatures in about NPD suggested that the combination of technological innovation, pressure on time to market and increasing customer demands urges manufacturing companies to shorten their product development process (Molenaar *et al.*, 2002). McDonough *et al.*, (1999) asserted that organisations involved with NPD process face pressure to reduce their development cycle time and costs, without sacrificing innovation. Barton and Krause (1985) stated that time to market has become critical in the highly competitive global environment and driving the need to respond quickly to customers need. Another challenge in NPD is how to acquire knowledge and manage sources of uncertainty in order to reduce the risk of failure of either the project or the ensuing product, (Cooper, 2003). Increasing product complexity increases the risk of product failure. However, despite the extensive testing of products, it is impossible for failures to be totally eliminated from a product. Therefore, when developing new products, the challenge is to reduce the chances of product failures. There is a need for a continuous improvement in product development process which acts as a proactive strategy for preventing failures from occurring and at the same time maintains product quality and reliability. Research conducted by Barclay (1992) indicated that product development process needs on-going improvement activities. Bessant and Caffyn (1997) define continuous improvement as "an organization-wide process of

focused and sustained incremental innovation". It involves set of activities that enables an organisation to improve its performance (Bessant *et al.*, 2001). One such activity is learning from experiences, for example capturing and using field failure data.

To survive in the competitive global and dynamic environment, products brought to the market must be better, faster and cheaper. This requires the product development process to be managed efficiently. Regardless of the type of product being developed it is subject to various risks which can lead to reliability problems. The next section describes quality and reliability improvement in the product development process.

2.4 Knowledge management in process improvement

Improving the service-to-design field failure feedback process requires understanding how to manage the knowledge created during the product development and service processes so that it can be shared and reused for product improvement. This section provides an understanding on knowledge management in the context of acquisition, dissemination and reuse during product development/improvement process. There is large number of definitions which differs in meaning within the knowledge management field. However the various definition of the term knowledge has led to different perspectives on how knowledge is managed within business processes. This section begins with the definition of data, information and knowledge

2.4.1 Defining data, information and knowledge

Data, information and knowledge are words often used interchangeable. It is important to understand the difference between these terms as they are relative within their context of use. According to (Groff and Jones, 2003) data is raw in nature and it's without context. It has no meaning beyond its existence. Maier *et al.*, (2005) described data as a "*symbol that are ordered to an elementary description of a person, thing, event, activity or transaction in the perceived reality or imagination of a person*". Data can be recorded, categorised and stored without conveying any specific meaning. Information on the other hand results from adding some meaningful context to the data, often in the form of a message. Therefore, Information is data that has been given meaning by way of context. The term knowledge is often used vaguely within organisation and within the subject of knowledge management. Knowledge is the combination of data and information that guides the action of a person. According to (Schreiber *et al.*, 2000) knowledge is used by a person to carry out tasks and create new information. This statement supports Davenport's definition of knowledge as "*information that has been combined with experience, context, interpretation, and reflection*" (Davenport, 1997).

2.4.2 Knowledge management

Existing literature on knowledge management have presented a number of different perspectives from which researchers and practitioners have approached the management of knowledge. A knowledge management process consists of knowledge acquisition, innovation, integration, protection, and dissemination (Lee and Yang, 2000). Knowledge acquisition is the process of learning, filtering new information, and storing the information for future retrieval. Acquiring knowledge required for new product development can be time consuming. Despite this, literature asserted that firms that are able to encourage knowledge acquisition can also increase new product innovation. Knowledge dissemination in organizations is fundamentally driven by the communication processes and information flows which are explicitly integrated in facilities such as IT systems and the internet/intranet. The dissemination of knowledge enables cross functional NPD team within an organisation to understand each other better, improve their ability to cooperate, collaborate and encourages interdisciplinary communication. Knowledge dissemination is however, a company-wide effort that should involve all employees. Hence, top managements should foster a knowledge sharing culture within their organisations that encourages the dissemination of both tacit and explicit knowledge in order to improve the new product innovation.

2.4.3 Knowledge sharing and reuse

Knowledge sharing involves making the required information available at the right time, and in the right format. Without access to accurate, relevant and up to date information, mistakes and duplication of effort will continually be made on many aspects of the product's design and development projects (Cormican and O'Sullivan, 2003).

Within a cross-functional NPD project, the expertise and skills are often distributed across individuals and groups, both internally and externally, hence, knowledge sharing is a necessity and the ability to facilitate knowledge sharing is crucial to success (Clark and Fujimoto, 1991; Lamming, 1993). Effective product development also requires that learning and knowledge from past development products be incorporated into the development of future new products (Marsh and Stock, 2003). Knowledge obtained from past development activities are usually tacit. Therefore, involving process experts with appropriate experience from past development projects into current projects is a method of transferring and reusing knowledge across product generations.

During product development process, regular communication and collaboration is required between project teams. Sharing knowledge between cross functional product development teams can help in problem solving, making design and cost trade-offs, improving manufacturability, and producing a higher conformance quality (Takeishi, 2001). However, this exchange of knowledge is not automatic; it requires processes that facilitate the use and transfer of knowledge across functional and organizational units. For example, socialization mechanisms are recognized as a key means of facilitating the flow of knowledge among firms (Lawson *et al.*, 2009; O'Donnell, 2000), enabling each partner to learn about the other's culture and to adjust its actions accordingly to establish successful outcomes. Socialization mechanisms such as team meetings, cross-functional teams, and joint workshops are use for connecting individuals across both parties. This enables close interaction

among team and creates a network of interdependent social communication whilst increasing the level of mutual trust and respect across the development teams (Cousins and Menguc, 2005). These interactions would as a result, lead to information exchanges within the cross functional team. This might be more frequent, relatively informal, higher quality, and occur earlier in the development process.

A method for taking advantage of existing knowledge is through the transfer and reuse of existing firm-specific knowledge among different individuals or groups within the organization (Watson and Hewett, 2006). According to Jones and Jordan (1998), knowledge sharing and transfer depends on personal networks and the willingness of individuals to share. A great deal of what people learn and what the organisation know results from interaction among and between team members.

Knowledge reuse is defined by Alavi and Leidner, (1999) as *"using existing knowledge generated by either by an individual or a group within an organisation in order to be more effective and productive in their work"*. Based on this definition the reuse of knowledge could prevent the repetition and duplication of work. This existing knowledge is often stored in knowledge repositories or databases so it can be accessed and reused by anyone who needs it within the organisation. The availability of a knowledge repository does not warranty successful knowledge management. Successful knowledge management depends on many factors such as the knowledge sharing culture that exists within an organisation (Davenport *et al.*, 1998) and the employees' willingness to share their knowledge through knowledge repository which often widely available to employees within the organisation (He *et al.*, 2009). In addition, knowledge recorded in the repository must be in a format that is useful and usable by anyone who needs it. Despite the criteria achieving successful knowledge management, Ofek and Sarvary (2001), suggested two benefits of knowledge repository which are: it saves time and cost through reusing existing knowledge rather than creating new knowledge from scratch. secondly, it can lead to the creation of new knowledge that improves the quality of the services/products offered by an organisation by using existing knowledge as a starting point. Furthermore, in order for knowledge repository to be effective, there must be an up-to-date contribution of knowledge to the system on a regular basis and the knowledge from the system must be acknowledged for reuse (Watson and Hewett, 2006, Goodman and Darr, 1998).

2.4.4 Role of Knowledge management in NPDP

A number of authors (Nonaka and Takeuchi (1995), Griffin and Hauser (1992), Davenport, 1993) acknowledged that effective new product development processes involve continuous sharing and utilization of knowledge and as thus become a focus of emphasis for organisations (Fliess and Becker, 2006; Handfield and Nichols, 2002). New product development is a knowledge intensive activity. A large amount of information and knowledge are required by designers to integrate customer requirements, ideas, and problems to make design changes. New product development is dependent on the firm's ability to apply knowledge and information towards the creation of knowledge to design and manufacture products that have value in the marketplace (Tannenbaum and Nash, 2002, Mohrman *et al.*, 2003). Cross functional units in product development uses expertise as a basis to approach problems in the process. Their knowledge is applied to problem resolutions in order

to generate new knowledge, which could be both tacit and explicit (Nonaka et al., 2000).

Product development can increase an organisations' competitive advantage by both exploiting the existing and exploring new knowledge (Floyd and Lane, 2000; Katila and Ahuja, 2002). Knowledge exploitation involves using existing knowledge in identifying problems and resolutions to it whilst knowledge exploration involves acquiring new knowledge in addition to existing knowledge (Revilla *et al.*, 2009; March, 1991; Katila and Ahuja, 2002). New knowledge can generate idea and possible solutions to problems (March, 1991) and can also be used in combination with existing core competences and experiences from past product development project. This would reduce the likelihood of failure and improve the reliability of the product (Levinthal and March, 1993).

Organizations learn through the knowledge acquire from their experience. The real value of knowledge within an organisation involves its flux, its dynamic usage, and its potential to promote continued learning (Pitt and MacVaugh, 2008). Nevertheless, if this new Knowledge is not applied or is not found to be useful in subsequent product development projects, it becomes obsolete (Davenport and Volpel, 2001). To avoid this problem, existing knowledge must be kept up to date and also needs to be sought as it often is mostly not freely disseminated.

Knowledge in NPD process model is often distributed, rather than centralised and often tacit, located in the minds of the process expert (Alavi and Tiwana, 2002; Kreiner, 2002). Though, both tacit and explicit knowledge are required for developing organisations competences. Pitt and Macvaugh (2008) argue that processes for managing knowledge should not be limited to formal, standardised "best practises" in order to optimise performance. Informal and other useful methods should also be considered. In addition an organisation also needs to know what it does *not* know and how to close their knowledge gaps.

The author believes knowledge management plays an important role in service-to-design product field failure feedback process, however, the concept of knowledge management would not be further explored in details as the problem identified in the scope of this research highlighted the need for improvement to the feedback process operation as a whole, therefore the focus of this research is on feedback process management and not the management of the knowledge within the process.

2.5 Quality and reliability improvement

2.5.1 Product Quality

The definition of quality has been the subject of much research and both researchers and practitioners have offered various opinions on what quality means. However, it is evident from existing literature that quality is subject to different meanings by different people. A number of quality gurus defined quality as follows: conformance to requirements and zero defect (Crosby, 1979), fitness for use (Juran, 1992), continual improvement (Deming, 1988), degree to which a set of inherent characteristic fulfills requirements (ISO 9000) and best for customer use and selling price (Feigenbaum, 1986), meeting customer requirement (Oakland, 1993).

According to Deming (1988) testing of a product in a laboratory is not enough to demonstrate how a product will react when in actual use by the customer. He further asserted that product quality should be established based on three criteria which are:

- The actual product
- Customer usage and experience such as how the product is installed and maintained by the user and
- The user manual, customer service, availability of spare parts

Managing quality improvement activities in the product development process can be seen as a sequence of activities that supports adding value to both the process and the products that have been developed. The increasing customer requirements means their expectation of a product and/or service in terms of conformance, reliability, dependability, durability, interchangeability, performance, serviceability, user-friendliness, safety, environmental friendliness is also increasing (Dale, 2003). Understanding the customers' quality experience would enable the product development team to establish how well the product is functioning in the field and how well it meets the customers' requirements. Customer perception of the product quality is determined by how well the product conforms to specification and fits its intended use, and also by product reliability over a period of time (Juran and Blanton, 1999). Customer satisfaction is decided both by the value and performance of product and by the quality of the experience the user has with the product throughout the service life of the product (Markeset and Kumar, 2002). In today's competitive market, the customer is considered as king, because they have more options to go to another competitor and their expectation is higher than ever. This means that unless a company is meeting those expectations and delivery 100%, customers' loyalty is uncertain. Therefore companies are always striving to live up to those expectations and differentiate themselves from competitors. As a result there is a need for continuous improvement in all business operations within an organization. Figure 2-3 illustrates the quality continuous improvement process.

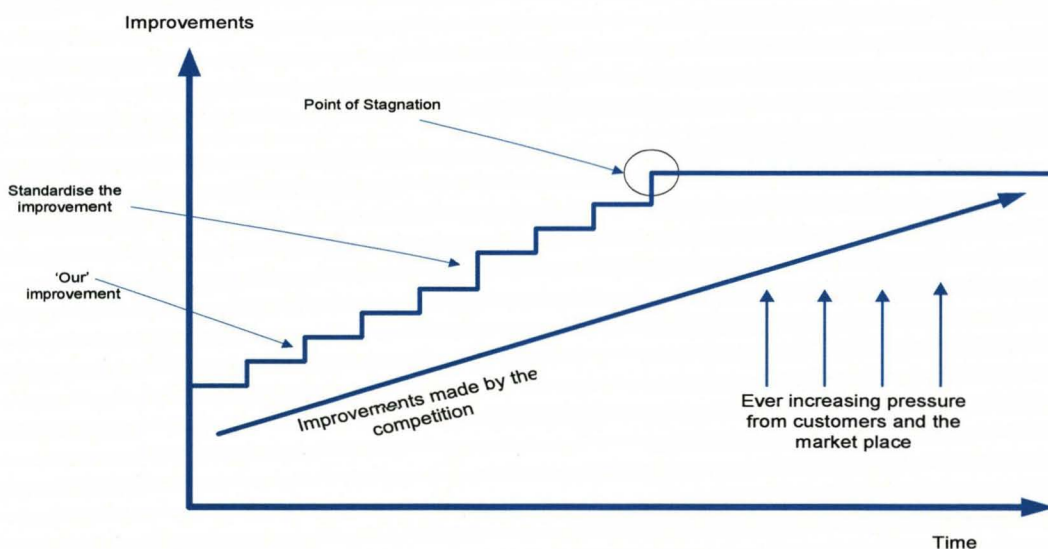


Figure 2-3: Quality improvement: a continuous process (adapted from Dale, 2003)

Research on quality improvement in literature often refers to a wide range of management approaches for which quality improvement is a key issue. Quality has played a fundamental role in influencing organisational competitiveness. Quality management in product development requires the commitment of the entire stakeholders involved in the development project. Continuous quality improvement activities in the new product development process enable an organization to achieve a competitive advantage (Rajiv & Sandeep, 2005).

2.5.2 Reliability

To provide a better understanding of reliability, first some definition of reliability will be established, then the need for reliability improvement would be discussed. Reliability is the ability of a product or system to perform as intended within a specified time of its life cycle (Moss, 2005). Lewis (1996) further defined reliability as performing as intended under a given set of conditions. However, Brombacher (2000) asserted, that the intended purpose for users is often different from that of a manufacturer. In product development projects, product reliability is an important issue and the increasing product complexity contributes to the increase of product failure. It can be argued that the reliability of a product conveys that the product performs and operates successfully with the absence of failure. The theory of reliability deals with interdisciplinary approach to the understanding of failure mechanisms. There are various aspects to reliability which includes reliability modelling, reliability analysis and optimization, reliability engineering, reliability science, reliability technology and reliability management (Blischke and Murthy, 2003). However this thesis is concerned with reliability analysis and management;

- **Reliability analysis** is categorised into two; quantitative and qualitative, the former is used for the verification failure modes and causes that contribute to product unreliability. The latter is concerned with real failure data which is either from test programs or field operations in conjunction with mathematical models to produce quantitative estimates of product or systems reliability Blischke and Murthy (2003) p4.
- **Reliability management** “emphasies the business viewpoint and is concerned with management issues in the context of managing the design, manufacture and operation and maintenance of reliable products and systems” (Blischke and Murthy, 2003) p4.

Good product reliability can only be achieved through good design and manufacturing practise. Predicting the reliability of a product can only be based on field data. However, uncertainties and “noise” in data often cause most organisations to make less use of such data (Loll, 2006).

Product reliability is a critical factor affecting the customer’s perception of product quality and ultimately impacts on market share. Organisations could lose market share and business opportunities when customer satisfaction is not met. Yang and Cekecek (2004) stated that an organisation needs to satisfy customer requirements and gain competitive advantage by improving product design through focusing on

weaknesses in the product. The reliability of a product is influenced by the approach taken during the design and development stage. Therefore the utilization of techniques such as FMEA can have an impact on the achievement and improvement of product quality and reliability. Figure 2.4 illustrates the reliability of a product over its lifecycle.

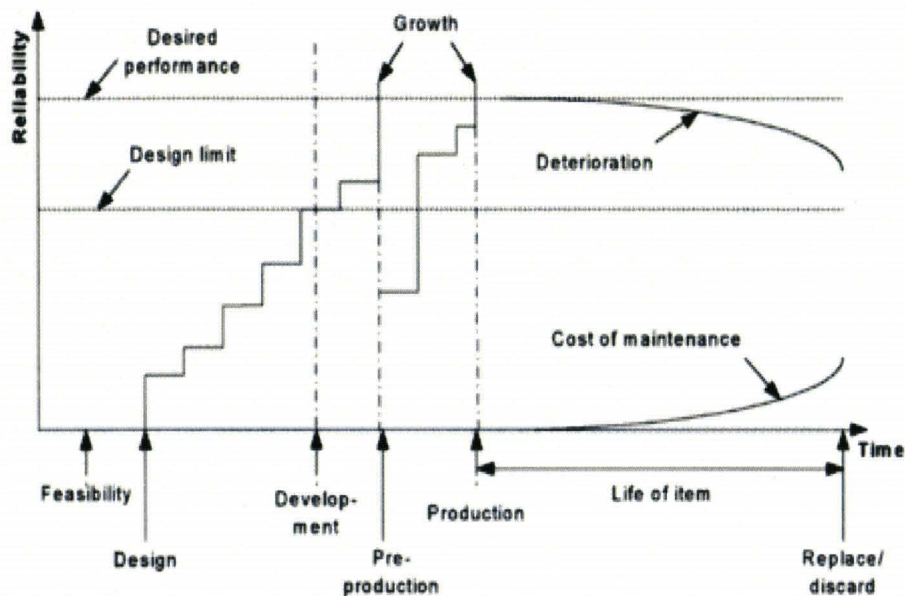


Figure 2-4: Product reliability over the life cycle (Blischke and Murthy, 2000)

Reliability is sometimes referred to as 'quality in the time dimension' because it is determined by the failures that do or do not occur during the life of the product. An important task in reliability engineering is to make design, development, and manufacture more reliable. To achieve this, it is necessary to anticipate and prevent potential failures from occurring (Connor, 2000). For many engineering products the quality of operation and maintenance also influences reliability. Reliability must be managed as an integral aspect of product design, development/test, and manufacture. It is necessary to identify reliability problems in an early phase of the product development. This would help in preventing problems from occurring when product is in use by the customer. However, not all problems can be detected, other reliability problems can still occur during usage in the field.

The reliability problems that occur in the field should be integrated into the activities conducted during the product development process so that a continuous learning process can be established. Brombacher *et al.*, (2005) establishes two types of quality and reliability problems which are;

- *Hard reliability problems which involve situations where the product is unable to meet both the explicit (technical) product specifications and customer requirements.*

- *Soft reliability problems which involves situations where a customer explicitly complains about the (lack of) functionality of the product despite the product meeting its explicit specifications.*

Brombacher *et al.*, (2005) further classified reliability problems into three dimensions which are time, statistics and specifications. Figure 2.5 below illustrates the quality and reliability reference model as proposed by Brombacher *et al.*, (2005).

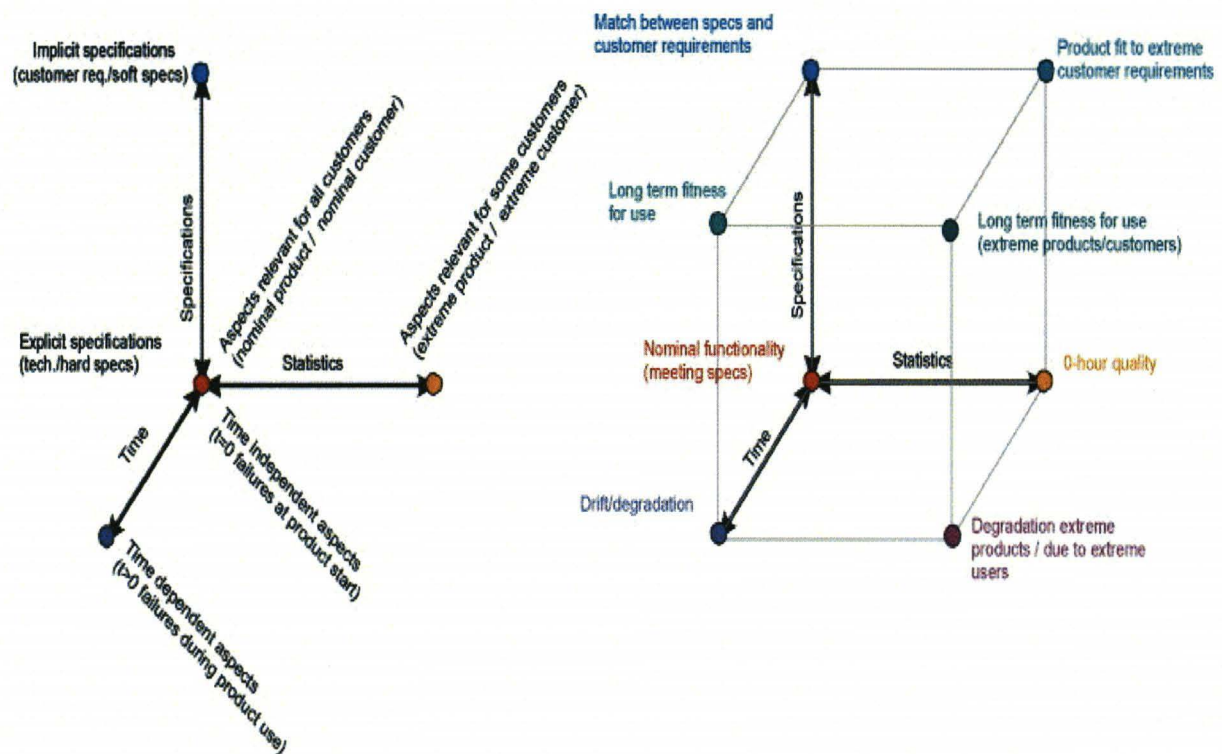


Figure 2-5: The Quality and Reliability Reference Model (Brombacher *et al.*, 2005)

Time refers to the period of product usage by customers. Statistics from field data refers to groups of customers that use the product. Specifications refer to technical/hard specifications and to soft specifications. Therefore, a broad range of reliability problems can be presented by using the reliability reference model.

2.5.3 The need for reliability improvements

Trends in the industry make it difficult to achieve product quality and reliability targets in the product development process, however, both quality and reliability of product plays a key role in industry (Ion and Sander, 2005). This difficulty has led to unanticipated product failure, which might also lead to a customer complaint (Ouden *et al.*, 2006). Research conducted by (Ouden, 2006) also identified that customer complaints are related to both technical and non technical failures. Ulrich and

Eppinger (2002) also argued that the manufacturers' attempt to reduce time to market has led to the omission or neglect of some testing activities. This means that potential risks may have been overlooked and as a result lower quality, unreliable and immature products have been released into the market. Reliability improvement involves feeding back subsystem and component level reliability information to design engineers to improve future generations of a product. The reliability improvement of products can also be achieved through lessons learned from product testings, reported field failures, technological improvements, etc. (Magniez, 2007).

Reliability improvements can be affected either by design changes in products or by using alternate parts, processes or suppliers. Examples of such include improved design using an older technology, implementation of developing technologies within an older design or the implementation of new modelling and analysis techniques that could be used to improve reliability of products (Tiku, 2005).

Jones and Hayes, (1997) suggested that before any quality and reliability improvement can be made to a product it is important to assess the current reliability in the field, which can be achieved by collecting field failure information throughout a products' life and performing analysis on this data. At the different stages of the product development process reliability related information, especially on how existing products are performing in the hands of the customers, should be available and obtained for making design changes.

A number of industrial and academic experts have developed tools and methods which aim at addressing problems with managing product quality and reliability. Examples of such tools are six sigma, control chart, quality function deployment, total quality management, failure mode and effect analysis, etc. These quality tools and techniques are needed throughout the product development lifecycle (Ganesh *et al.*, 2005). With the aid of these mentioned tools and techniques most organisations have detailed processes in place for addressing customer complaints.

This thesis will only examine the failure mode and effect analysis technique which would be discussed in section (2.5). The literature has emphasised a number of benefits that can be derived from using such tools on improving business performance (Bhote, 2000, Schippers, 2000). However, the efficiency of these tools relies on the availability of detailed and accurate information. According to Ganesh *et al.*, (2005) when little information is available, some quality tools and techniques cannot operate optimally and thus become redundant.

2.6 Quality tools and techniques

The purpose of applying quality tools and techniques during new product development process is to achieve quality assurance. The use of quality tools and techniques for product improvement is important in reducing defects in a product and contributes to the engineering knowledge of the product design in the early stages of the product development process. Tennant & Roberts, (2001) suggested that preventive actions must be applied at this stage to capitalize on the strength of influence, such as, low cost of making design changes that exists at the early stage of new product development process.

Quality tools and techniques are practical methods, skills, means or mechanisms that can be applied to tasks within a process, to facilitate change and improvements to that particular process (McQuater, 2000). Table 2-2 below illustrates the commonly used quality tools and techniques for quality improvement.

Table 2-2: Common used tools and techniques (Tari et al., 2004)

Seven quality control tools	Seven management tools	Other tools	Techniques
Cause and effect diagram	Affinity diagram	Brainstorming	Benchmarking
Check sheet	Arrow diagram	Control plan	Departmental Purpose analysis
Control Chart	Matrix diagram	Flow chart	Design of experiments
Graphs	Matrix data analysis method	Force field analysis	Failure mode and effects analysis
Histograms	Process decision	Questionnaire	Fault tree analysis
Pareto diagram	Programme chart	Sampling	Poke yoke
Scatter diagram	Relations diagram		Problem solving methodology
			Quality costing
			Quality function deployment
			Quality improvement teams
			Statistical process control

Basu (2004) described tools and techniques as a double-edged sword, effective when used properly and ineffective when misused. For example, an effective use of tools and techniques can help to anticipate problems in the process before they occur. On the other hand, factors such as inadequate training, management commitment of resources, employee mindset, and poor application can result in ineffective use (Basu and Wright, 2003). However, increased communication is one

of the most important effects of its usage. Clark and Fujimoto (1991) argued that better communication among team members could lead to a reduction of making technical changes in the product development process. In an attempt to improve product quality, quality assurance techniques such as failure mode and effect analysis have been adopted by many organisations.

2.7 Failure Mode and Effect Analysis

A failure mode and effect analysis (FMEA) is an engineering technique used for defining, identifying and eliminating known and/or potential failures, problems, and errors for example, from components/parts/functions in the system, design, process, and/or service before they reach the customer or lead to an undesirable outcome such as production loss, injury or accident (Omdahl, 1988; Stamatis, 2003; Sharma *et al.*, 2007). The FMEA methodology helps to analyze the effects these failures have on the system and how to correct and/or mitigate the failures or effects on the system. Stan Jakub (1998) described FMEA as a process that categorises and documents an engineer's design intent by considering what can happen when a product design fails, how it can fail, what can be done to prevent it from failing, what are the risks involved with the failure and finally, how can the design be improved using established practises and state of the art methods. The challenge of conducting FMEA is to build in quality and reliability early into the product development process.

The initial purpose for the development of FMEA was to fully understand the functionality of a system in order to improve the system reliability so that the product is right from the outset. Also, to identify the different failures and modes of failure that can occur at the component, subsystem, and system levels and to evaluate the consequences of these failures. The fundamental concept of risk of failure analysis is to address the questions (Chao and Ishii, 2003):

- What things can go wrong?
- What are the possibilities of them going wrong? and
- What are the resultant consequences?

FMEA can be applied to a wide range of problems that occur in processes and therefore, it is a means to achieving a better quality product which is why it is adopted in diverse industries such as automotive, medical device manufacturing, aerospace, chemical processing, etc. According to a survey conducted by Chao and Ishii (2003) many companies are aware that design errors are major sources of quality failure. Therefore techniques such as FMEA are vital for the identification and prevention of failures.

2.7.1 Types of FMEA

There are three main types of FMEA as mentioned in the literature (Stamatis, 2003; they are:

- System FMEA (SFMEA): used to analyze systems and subsystems in the early concept and design stage
- Design FMEA (DFMEA): used to analyze products during design stage before they are released to manufacturing (more detailed than SFMEA)
- Process FMEA (PFMEA): used to analyze manufacturing and assembly processes.

The different types of FMEA have similar thought process but differ in the areas being analysed.

2.7.2 How FMEA is conducted

FMEA is conducted by a cross-functional team of experts from various departments who are qualified to constructively critique a design through a creative brainstorming session and offer a potential solution (Dovich). The FMEA team is formed at the planning stage of a new product development process. The team analyses each component and subsystem of the product for the failure modes. Then, the potential causes and effects are determined. The risk of each failure is prioritized based on the risk priority number (RPN). The early use of the methodology during product development process, in particular during the design process, allows the engineers to design out failures and produce a quality and reliable product that meets customer satisfaction. An early change to design is more cost effective. However, Price *et al*, (1995) asserted that FMEA is often carried out late in the design cycle after the design prototype has been built. In addition the consistent use of FMEAs also captures historical information for use in future product improvement (Crow, 2002). Figure 2-7 shows the general procedure suggested by Teng and Ho (1996) to perform an FMEA.

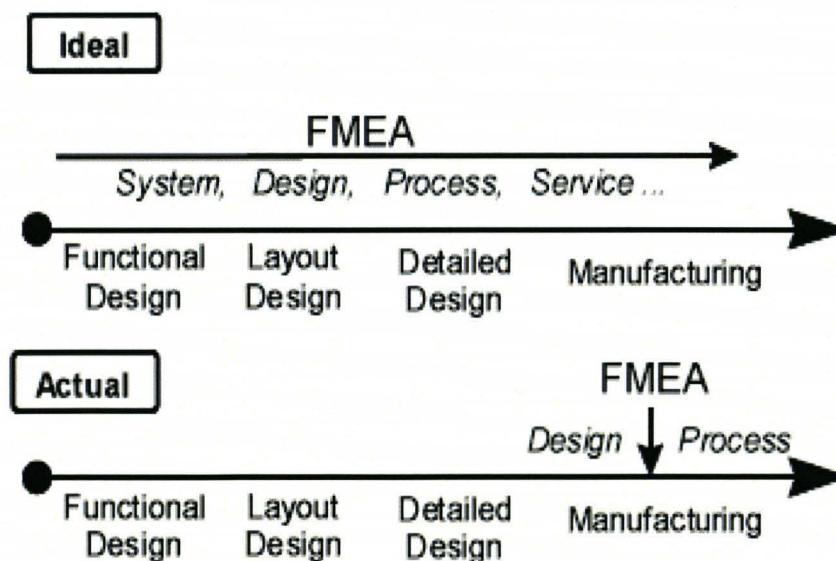


Figure 2-6: Comparison of ideal and actual deployment of FMEA (Kemta and Ishii, 1998)

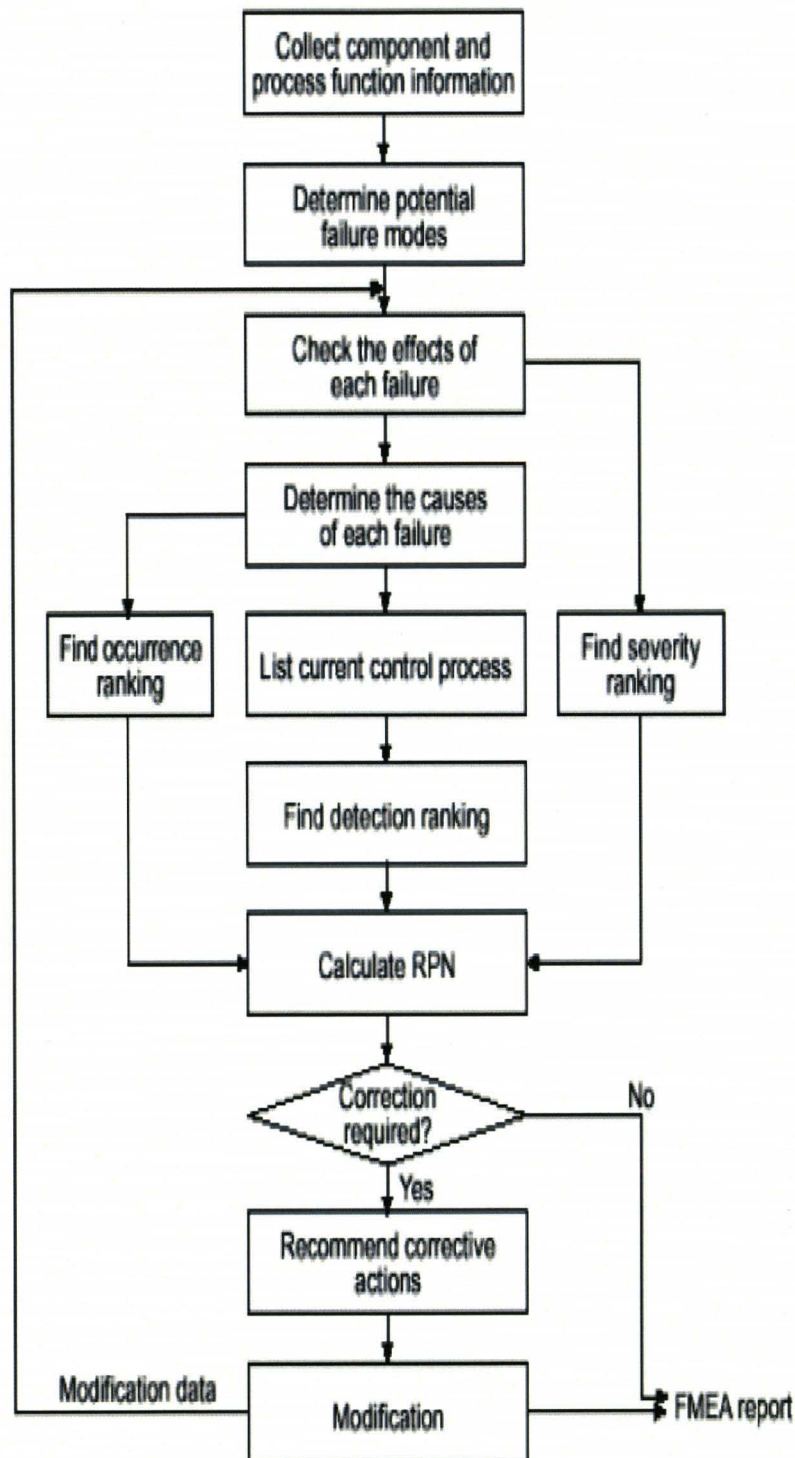


Figure 2-7: FMEA Procedure (Teng and Ho, 1996)

Steps in performing an FMEA require a logical sequence of events to be followed and actions to be documented. Teng and Ho (1996) suggested that failures listed in the FMEA worksheet should include failures identified from both end-user customers and internal customers and from data on similar products or process. Table 2-3 illustrates a typical template of an FMEA worksheet.

Table 2-3: FMEA Worksheet Headings

Item	Item Function	Failure Mode	Causes	Controls	Failure Effect	Initial Conditions				Current Controls	Recommended Corrective Action	Corrective Action	Action Results			
						S	O	D	RPN				S	O	D	R P N

As shown in table 1, the item column should list system, subsystem, module, part or component, which functions are considered, functions should describe the functions of each items. Failure mode should describe situation in which an item could potentially fail to meet design functions. The causes of failure should define root causes; there could be more than one potential cause per failure mode. The effect of failure describes what would happen if failure occurs, and determines the severity of the failure mode. Risk priority number (RPN) is a decision factor based on the product of three ratings: occurrence, severity and detection. These ratings are scaled with numbers between 1 and 10. It helps to identify critical items and prioritisation of failures through the calculation of the severity, occurrence and detectability of the estimated features. Current controls describe methods, tests or procedures which are in use for detecting failure modes and their causes. Recommended correction involves proposing solutions to eliminate or minimise the potential risks, amongst which the appropriate corrective action would be selected and conducted. Finally, after taken action, the severity, occurrence and detection should be re-rated and a new estimation should be calculated to produce a decreased RPN value.

2.7.3 Benefits of FMEA

According to Stamatis (2003) a good FMEA would help to achieve the following:

- Identify known and potential failure modes
- Identify the causes and effects of each failure modes
- Prioritise the identified failure modes according to the risks priority number (RPN) – the product of frequency of occurrence, severity and detection.
- Provide corrective actions

Other benefits of FMEA as identified in the literature are that it provides detailed insight into the systems interrelationships, and it is a useful tool for reliability

analysis. Dale and Shaw (1990) identified the benefits of FMEA as it provides improvement to process quality and reliability, focus on failure prevention rather than correction, which as a result leads to customer satisfaction and cost reduction in product design due to less need for redesign or modification. Benefits identified by Crow (2002) include emphasizing problem prevention, documentation of risk and actions taken to reduce risk, providing focus for improved testing and development, acting as a catalyst for teamwork and idea exchange between functions, prioritising product/process deficiencies and capturing engineering knowledge. Another benefit of FMEA as identified by Otto and Wood, (2001) includes; provision of additional information to aid the planning of thorough and efficient design improvements and development testing, provision of an open issue format for recommending and tracking risk reducing action and providing future references to aid in analyzing field concerns, evaluating design changes, and developing advanced designs.

2.7.4 Limitations of FMEA

Traditional FMEA, although very effective in analysing system failure modes, suffers from a number of limitations. According to Wirth *et al.*, (1996), the method has two fundamental weaknesses. First, there is no guideline on how to conduct an FMEA, hence the methods employed vary from one practitioner to another. Second, all FMEA-related information is recorded in natural language, thus each team member uses his or her own vocabulary.

Booth (1999) suggested that the limitations of FMEA falls under one or more of the following three categories which are; the process is conducted by the wrong people, it is done too late and finally it is isolated from the design process. Due to many relationships among the failure modes, effects, causes, current controls and recommended actions which require a large amount of in-depth analysis, repetitive and redundant data, FMEA is considered as a time consuming and complicated process. Bull *et al.*, (1995) stated the length of time involved in FMEA analysis is excessive. Montgomery *et al.*, (1996) stated that the traditional brainstorming process of FMEA is tedious, time-consuming, error prone and often inconsistent and incomplete. Sincell *et al.*, (1998) stated that the FMEA process is laborious and sometimes opaque. Russomanno *et al.* (1994) suggested that the FMEA team often does not understand the process and lacks adequate FMEA training and the FMEA process expertise is concentrated in the hands of relatively few specialists. Lee (2001), in his research, also identified that current industrial FMEA practise is limited in its usefulness and analytical capability due to the spreadsheet based approach that is used for acquiring, representing and reasoning with system failure knowledge. One of the disadvantages of this approach is it hinders effective reuse of FMEA knowledge across design.

2.8 Product Failure

Product failures can be attributed to failure in the design and delivery processes, operational environment, or how the product is used. According to Petkova *et al.*, (2005) there has been a shift in the types of failure and the causes of failures over the years. Furthermore, a significant amount of reported failures are categorised as unknown, not verified and other causes. This shows the inability to clearly identify the root causes.

The term failure is often confused with the term fault, therefore various conflicting definitions exist. According to IEC 50(191) failure is the event when a required function is terminated (exceeding the acceptable limits), while fault is 'the state of an item characterised by inability to perform a required function, excluding the inability during preventive maintenance or other planned actions, or due to lack of external resources'. A fault is hence a state resulting from a failure. For the purpose of this research investigation product failure or fault is used interchangeably.

The definition of product failure in this research investigation is established as the inability of the product to perform its intended function.

There are various classifications of failures as identified by Rausand and Oien (1996) and Blache & Shrivastava (1994). They are;

- **Intermittent failures:** Failure that lacks of some function only for a very short period of time. The item will revert to its full operational standard immediately after the failure.
- **Extended failures:** A failure that lacks some function that will continue until some part of the item is replaced or repaired. Extended failures may be further divided into:
- **Complete failures:** Failures that cause complete lack of a required function.
- **Partial failures:** Failure that leads to a lack of some functions but do not cause a complete lack of a required function.
- **Catastrophic failures:** A failure that is both sudden and complete.
- **Degraded failure:** A failure that is both partial and gradual such as wear and tear.

As the components and sub-systems become more technically advanced and the number of components increases, the possibilities of failure also increases (Markeset and Kumar, 2003). It is impossible that failure may be completely eliminated from a product; the challenge is to effectively reduce the chances of product failures.

2.9 Role of after-sales service

An after-sales service is considered as a source of competitive advantage, business opportunity and an information provider to other functions in the product development process (Saccani *et al.*, 2006). Traditionally after-sales service constituted maintenance, service and repair. However, as the scope of product support has broadened over the years, it has also included aspects such as installation, training, maintenance and repair services, documentation, spare part supply, product upgrading, warranty schemes, telephone and online support, etc (Markeset and Kumar, 2003; Goffin, 1999). Oliva and Kallenberg (2003) argue that the need to integrate an after-sales service into core product offering is as a result of economic gains, customer requirements and competitive advantage. For example, in terms of economic gain, it has been indicated often in literature that after-sales service often generates more profits than product sales (Saccani *et al.*, 2006; Lewis

et al., 2004; Bundschuh and Dezvane, 2003; Alexander *et al.*, 2002) and is also a key differentiator for manufacturing companies (Saccani *et al.*, 2006).

Service is becoming an important aspect of many organisations' business, even if the organisation's core business is the manufacture of physical products (Blythe and Zimmerman, 2005). Most physical products often wear, tear, and deteriorate with age and use; in addition, the increasing product complexity means that it is almost impossible to design and manufacture a product that is maintenance free. The role of an after-sales service support is to ensure a product is functioning well for consumers over its life span. Trends in global competitive marketplace, increased customer demands and technological changes are forcing organisations to closely monitor and address issues on how to offer after-sales service support to their product delivery. Hence, manufacturing organisations that strive to succeed in their competitive environment are producing products that offers more value than their competitors through design, manufacture and most especially product delivery and support.

The role of an after-sales service is to respond to customers' complaints by providing support to customers about any problems they are experiencing with their product. An example of support provided includes product failure restoration, problem diagnosis, expert assistance to resolve a problem, problems with using the product, etc (Markeset and Kumar, 2003). Service provides product designers with reliability information about product generations on the market. Such information is used by product designers to identify and prioritise major reliability problems that have occurred in existing product generations or to prevent the problem from reoccurring in future product generations. According to Gronroos (2002) if customer problems are not resolved, they would become dissatisfied; therefore, the role of service is to recover customer satisfaction to its original state before the problem occurred.

After-sales is a prospective source of competitive advantage for an organisation (Gallagher *et al.*, 2005; Goffin, 1999), which also provides business opportunities and feedback information to other functions (Saccani *et al.*, 2006). Goffin (1999) identified the importance of the after-sales service as follows:

- Major source of revenue
- Essential for achieving customer satisfaction and maintaining customer relationship
- Provides competitive advantage through product differentiation
- Contributes to the product improvement processes and success rate of new products, through the feedback of field failures to the relevant product development team

Ensuring the quality of service support requires service personnel who are able to interact with customers and have appropriate skills to respond efficiently and effectively to customer needs.

2.10 Field Data

Field data are a rich source of information on product quality and reliability. It provides insight into the actual customer problems and product failures (Karroum,

2004). Field failures can be caused by interactions between various design parameters and process features of the individual components of the product.

If the causes of failures are diagnosed and reported accurately for each complaint, the data can be used to assess the field reliability of products and also to identify opportunities for improvement. However, due to the large number of components and the interactions between products, it is difficult to identify all of these relationships during design (Manner *et al.*, 2006). Field data represent crucial information related to the actual quality and robustness of the product as perceived by customers. Petkova *et al.*, (2005) asserted that information provided from the field on product failures is valuable if it is on time for operational use.

Furthermore, a study conducted by Simon *et al.*, (2001) suggested that data collected during the use of a product can be used to change the product design to attain better reliability and conformance to customers' needs. However, Manner *et al.*, (2006) argued that failures due to physical damage or misuse by customers are easy to detect during service operations, but many failures cannot be diagnosed visually or by other current inspection procedures. Therefore, such failures may be related to process and product discrepancies unknown in the design phase. In order to incorporate relevant field experience in the design and manufacturing of new products, increasingly detailed information needs to be retrieved from the field in a very short amount of time (Boersma *et al.*, 2004). Markeset and Kumar (2003) suggested that the collected field data can be used for developing future generations of products, but most importantly to remove or reduce critical weaknesses in the product design.

Literature on improving product quality and reliability using product field performance data, also referred to in this thesis as field data, is somewhat scattered and scarce. However, a number of authors have mentioned the importance of field data in improving product designs that serve to satisfy customer requirements on product quality (Petkova *et al.*, 2005; Manner *et al.*, 2006; Simon *et al.*, 2001; Lu *et al.*, 1999). These authors also identified in their research that market trends in the product development environment have influenced uncertainty with the quality and reliability of products in use. Petkova *et al.*, 1999; Petkova *et al.*, 2000; Molenaar, 2002).

According to Petkova *et al.*, (2005) there are two types of field data required in product development process; these are technical information and statistical information;

- Technical information aids the realisation of technical solutions for transforming ideas into actual products. It is also used for improving product quality and reliability that are below standard.
- The later type of data, which is statistical information, is used for monitoring the frequency of failures. Statistical information is essential for reliability prediction of new products. It can also be used to determine if an organisation is learning from the past to check if there are any differences in product quality over different types of products and over product generations.

In order to be able to use information on the field behaviour of previous products in the design of new products, detailed information of the product in use must be

obtained from the field as early as possible. A number of authors asserted that availability of field data usually takes a long time and is therefore too late to improve the product concerned or the next products generation (Kuijk *et al.*, 2007; Petkova *et al.*, 2005; Yang and Cekecek, 2004; Ouden *et al.*, 2005). Knowledge about field failures is valuable because the failure occurred under true conditions of use with the customers. However, one of the major problems with field failure data is that it does not always cover the true condition of use such as customer abuse of the product, which they would not admit to when they report the fault. Also parts can be reported as defective initially and when the service engineer attends to the call, no problem is found. Field data contains more information than other tests for the reliability of products in actual use, (Yang and Cekecek, 2004). The analysis of the field data is important for manufacturers because it provides very useful information that can be used in business operations and design activities. Yang and Cekecek (2004) stated that when constructed properly and maintained appropriately; field data may be used to predict future claims, to estimate field reliability and to evaluate design changes.

One of the challenges faced by the new product development organisation is how to utilise field data in order to prioritise the improvement areas of the product allocate their limited resources in a way that would add value and yield highest benefits (Yang and Cekecek, 2004). According to Ahmed (1996) improvement in product quality and reliability will bring about a reduction in warranty parts and labour cost. However, Petkova *et al.*, (2005) argued that available field data must be comprehensive enough for quality improvement actions. Field data can be integrated with product and process design as an important feedback source. This would enable a manufacturing organisation to obtain the most benefit from field data in terms of lessons learned.

2.11 Service field feedback

Service feedback is the information received by the product development team from the field once a product is on the market and in use by the customer. This field feedback information is important for product developers because it would allow them to learn from their design actions and indicate essential areas for product improvement (Kuijk *et al.*, 2007). Even though various tests are conducted during product development to assess the quality and reliability of products, these tests cannot fully replicate real life usage, therefore the products are bound to malfunction at some point during its life span when in the hands of the customer. Petkova *et al.*, (2005) asserted that it is not always obvious during product development how customers would use the product. Field failure feedback is useful in verifying product performance through gaining insight into actual product usage (Kuijk *et al.*, 2007; Molenaar *et al.*, 2002). This knowledge about product usage is considered to be a significant enabler for product improvement (Kuijk *et al.*, 2007)

Feedback information collected from after-sales activities may constitute essential input to product and service development (Thoben *et al.*, 2001; Armistead and Clark, 1992; Saccani *et al.*, 2006). The field feedback information may be relevant in reducing total quality cost, speed-up the product development and reduce time to market for new products (Saccani *et al.*, 2006, Stalk and Hout, 1990). According to Saccani *et al.*, (2006) the management of field feedback information is crucial for supporting the redesign of products and components and the development of new

products, sales and promotion activities and customer relationship management activities.

The suitability of current service processes for collection of sufficient and relevant field failure feedback for use in product improvement has been criticised in some literature (Visser et al., 2006). Literature indicated that the usefulness of the field feedback from service to the development team depends on how the information is communicated so that it is pro-actively used in the development process. Kuijk *et al.*, (2007) asserted that field feedback must be communicated in an appropriate manner. Ouden et al., (2005) asserted that although the field data may be documented correctly, attention needs to be paid to how the field information is disseminated to the product development team. Kuijk *et al.*, (2007) suggested that it must be communicated in an appropriate manner, however, Busby (1998) identified that feedback to designers was often unreliable, delayed, negative and sometimes missing. In addition designers often fail to learn from available feedback; as a result existing failures reoccur in new design.

Organisations spend huge amounts of money investigating customer complaints on product failures in the field, in order to find out what problems are occurring and take preventive action for the future. Feedback information about the root causes of failures are necessary to ascertain the type of failure, determine the impact of the failure on the overall product reliability and determine possible solutions for the failure in current or future product generations.

2.12 Feedback Process

The feedback process provides critical performance information on product failures in the field to individuals or the organisation during and/or after a particular performance period.

To improve product development processes, a feedback process must be implemented. Petkova (2000) argued that feedback control loops are necessary in product development to check whether the output of the business process is in accordance with the initial specifications. Learning from experience and assigning actions to failure consequences is normal practise in product development organizations. Research has shown that feedback to designers is often delayed, negative and sometimes missing or not available at all. As a result of not learning from product failure in the field, designers repeat previous errors in the design of new product; hence, product quality is affected and not improved.

The field feedback process needs to fulfill certain criteria to provide adequate information for product improvement. An example of such criteria is that its content should be clearly defined according to the users of the information. According to Magniez (2007) the development of an innovative product requires high quality feedback and control loops in order to achieve efficiency of the total business chain. Continuous improvement of product quality and reliability demands different channels of field failure feedback, so that performance data on the product in use can be captured, analysed and implemented in new product development. Another criterion as asserted by Petkova *et al.*, (1999), is that the structure and quality of the

feedback process can determine the ability of an industry to prevent failures from recurring in future products.

Existing literature on field failure feedback process indicated that the effectiveness of a feedback process from service to the development process depends on its continuity, timeliness, accuracy, and relevancy and is understandable (Busby,1998; Petkova,2000; Molenaar et al., 2002). Longenecker and Scazzero (1994) suggested four benefits of a feedback process, they are: to monitor the progress of a product or process performance, being useful for making changes and problem solving, to motivate stakeholders and to provide a basis for future goal-setting activities. The diagram in figure 2-8 below illustrates the flow of feedback information in product creation process.



Figure 2-8: Information flow in product creation process (Molenaar et al., 2002)

The process of feeding back on product failures to the development team also has its limitations. Busby (1998) identified categories of problem with the feedback process, which are:

- Design organisation planning design activities in ways that were at odds with outcomes of previous activities.
- Repeating design related errors such as errors made by others and reusing problematic design without knowing. This shows that the design organisation fails to learn from experience.
- Unreliability in feedback received by the design organisation for example, inappropriate categorisation of product faults and mis-diagnoses of problems, all of which can result in a decline in feedback seeking/giving behavior.
- Feedback is often negative and consists of complaints and criticism, instead of confirmation of good outcomes. As a consequence, it can result in a decline in feedback seeking.

It is evident that the first three categories of problems with the feedback process are information related problems whilst the fourth category is more of a motivational problem. Problems with feedback can arise in different ways, for various reasons and have different consequences. However, Busby (1998) concluded that all the feedback problems arose from effects such as limitations of individual performance like bypassing the peer review, defects in organisational design, which might be absence of training and records of past outcomes or experiences, and characteristics of task structure such as the delay between decision making and observing the consequences.

Feeding back the performance of a product in the field is an essential element of the continuous product improvement process. If field failure data is not reported, design engineers will not know the consequences of their design and little action will be taken to improve it. The extent of the feedback provided to the designer would inform them of the level of customer satisfaction and the effort required to improve the product in order to satisfy customer requirements. Therefore field failure feedback must be provided to the functional departments who have an important role in analysing and providing a solution to the problem and delivering customer satisfaction.

2.12.1 The need for a field feedback process from service-to-design

Factual information about product quality and reliability problems can only be obtained from field service operations. Preventing product failure risk in new products requires an organisation to have access to accurate information on actual performance of existing products in use by their customers. The evaluation of this failure data would enable countermeasures to be implemented during the product development process to predict possible failures, and redesign the product to prevent similar failures from re-occurring.

The capability of an organisation to prevent failures from reoccurring in a product requires an effective feedback process from service-to-design and other relevant departments, so that necessary information on product failure is available to enable design decisions to be made to reduce risks and assure product quality.

Products are developed to perform a particular function and to satisfy a customer's need for that function. Magniez (2007) argue that every time the product is used, failure mechanisms may be activated, either through failures inherent in the product

itself or the way the product is used by the customer. In line with this notion, the researcher argues that failures built into a product occur as a result of design engineers not foreseeing this potential failure at the design stage and assigning corrective actions to eliminate the failure from occurring. Rausand and Oien (1996) state that ensuring quality and reliability strongly depends on the analyst's ability to identify all the required functions, and hence all the failures, of the item that is subject to analysis. Analysts in this case would be either the designers or the product development team.

The need for anticipating feedback in order to reduce uncertainty and make better decisions in the early phases of the project is important (Bartezzaghi *et al.*, 1997). Furthermore, Bartezzaghi *et al.*, (1997) argue that the most valuable feedback is given by the actual product performance. Therefore, it can be argued that the actual consequences of a product design choice emerge only several months later, when the product is in use. According to Womack and Jones, (2005) these product field data should be included in the design and improvement processes. The overall goal is to integrate service issues into the overall product design "Design for Serviceability", and to respond to performance issues through design engineering change.

Ion *et al.*, (2006) also suggested four reasons for providing feedback of product field failure data to product development process, they are:

- The failure data can be used to assess whether the field complaints should lead to product recall.
- Field information gives the possibility to update predictions made earlier in the product creation process.
- Field reliability figures are valuable for a mutual comparison of the reliability of different (generations of) products. They demonstrate which product creation processes are fully under control and which processes need special attention.
- Early availability of the field feedback data offers the product development team the opportunity to assign immediate actions to problem issues. This prevents the same problem from reoccurring in future generation of new products.

Feedback processes used in literature often consist of a basic structure as shown in figure 2-9; it includes an action mechanism, feedback structure and measurement tools.

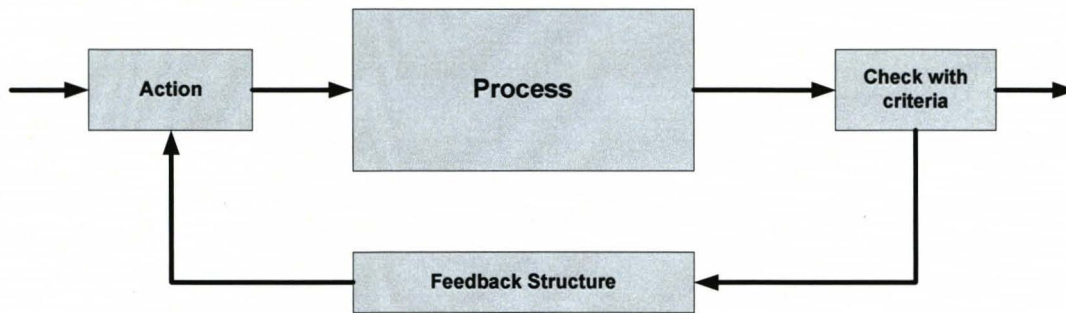


Figure 2-9: Feedback control loop

Despite the highlighted benefits of field feedback from service-to-design for improving new products generation, Petkova *et al.*, (2000), in their research on consumer electronic products, identified three major problems with feedback from service. They found that within companies that produce highly innovative products, the speed of the feedback on product performance in the field was not fast enough and often takes too long. Due to the increase of product time to market, the field feedback is too late. In addition, the quality of the information is poor. And finally the information available is not complete enough for use in product improvement.

2.12.2 Existing research in field failure data feedback

A number of researches conducted on product reliability improvement has emphasised the need for a feedback process. However there is limited research focus on how the actual feedback process from service-to-design through FMEA is conducted and how field failure data can be integrated into the FMEA process so that the analysis of results can be fed into a new design and used for improving product reliability. Existing research on the field feedback process lacks emphasis on how to effectively manage the process. In addition little research has identified what the critical features of a feedback process should entail. This section would examine existing research on field feedback process.

The majority of the research published on field feedback has been conducted within the consumer electronic industry. This research study will employ field feedback approaches used in the consumer electronic industry and apply it to a different industrial context which is the heating technology industry. This research would build upon the gaps identified in existing findings in the literature on the field feedback process in order to establish the antecedents of an effective service-to-design feedback process.

Zairi (2000) emphasised the value of feedback and stated that feedback should be assigned to designated teams within the organisation.

Visser *et al.*, (2006) investigated the suitability of current service processes for the collection of sufficient and relevant information to perform failure prioritisation within

the development process of consumer electronics and suggested the development of a new failure prioritisation model.

Boersma *et al.*, (2004) in their research identified that in order to incorporate relevant field experience in the design and manufacturing of new products, increasingly detailed information needs to be retrieved from the market in a very short time. To achieve this they developed a business model that can adequately capture information of a higher quality and in a more structured manner.

Brombacher (2005) identified that component-related reliability problems constitute only a minority of all product failures. He developed the concept of Maturity Index on Reliability (MIR) which analyses the response of a business process by looking at the chain of activities involved in handling product reliability related issues throughout a business process. A MIR model was developed to identify areas lacking quality information flow.

Yang and Cekecek (2004) stated that field data can be linked to product design as an important feedback source and thus suggested that a structured framework to establish this link is essential for manufacturers to obtain the most benefits from the field data. A model of the structure of the feedback process in terms of information flows was presented by Molenaar *et al.*, (2002); this model describes the chain of activities in the feedback process as a function of different drivers such as cost, time and quality. The author argues that by using the proposed Maturity index for the reliability model it is possible to visualise the information flows in a business process, as well as monitor the quality of the information and the dissemination delays for this business process.

Whaling and Kemp (2004) developed an electronic database tool to facilitate the integration of full life cycle product reliability and safety management. This system collects field failure data, tracks and drives corrective actions, pulls the lesson learned in the proactive analysis tools used in product development, drives product development to use the proactive analysis tools, keeps a library of proactive analyses to act as guides for future development, provides the proactive analysis for direct use by a root cause team driving to analyse and correct a field failure, and tracks and drives all activities. The main feature of this system is that it allows real-time feedback.

Petkova and Sander (2005) emphasised the quality and speed of the field feedback. They investigated the field feedback processes and how the improved relevance of the information collected and the speed can be improved. The findings from this research suggested that the speed of the current field feedback information structure makes it impossible to improve the next product generation using field information about current generation.

Jones and Hayes (1997) in their research asserted that before any reliability improvement can be made to a product it is necessary to assess how the current reliability in the field can be achieved by collecting field failure information throughout a product's life and perform analysis on this data. They developed a guide for the data collector about the correct methodology that can be used for data collection and gave examples of the kinds of analysis that can be done when sufficient data has been collected. However, they did not describe how to determine this sufficiency.

There is still little research which provides examples on how the actual feedback process from service-to-design should be conducted, the criteria for an effective feedback process and who should be involved, despite many articles on product development emphasising the need for it. However, the existing research on product improvements has presented a simplistic field feedback process model which lacks an in-depth analysis of the model and its applicability in product design improvement process.

2.13 Gap in Knowledge

From the literature reviewed, it emerged that increasing business pressures on product development process has lead to an increase in product failures. The literature on the product development process shows that there is a need for feedback of product failure data in the field to design engineers for improving existing and new product design, quality and reliability. Subsequently, customer satisfaction should be increased.

The majority of the research on field feedback is mainly within the consumer electronic industry. Existing research mainly focused on the quality of information flow and, the analysis of information in the product development process. A number of authors identified that field data is often limited in terms of quality; Busby (1998) stated that field feedback is often inappropriately categorised, incomplete and vague and not in a format which is readily available for use. However, existing research does not explore how the field failure data should be collected, recorded and disseminated for use in the product development process in order that the field data feedback quality is improved, relevant and usable by designers for achieving product quality and reliability improvements.

Many authors on field data feedback have classified field data into engineering information and statistical information. It can be argued that field failure is not always component related failure which is referred to in the literature as engineering information. Failure could occur as a result of the environment in which the product operates. Existing literature on field feedback lacks the emphasis on what field information should be collected. It has focused more on the technical aspect of feedback process but less on the management of the process.

The majority of the literature on field feedback focused on the use of the Maturity index on reliability. This model is used in analysing flow of information in feedback process and also for managing reliability problems. Existing literature emphasized the need for a feedback process of product failures from the field and its benefits for product improvement. However little attention has been paid to what should constitute an effective feedback process, and how the feedback process from service-to-design should be conducted and managed.

Literature often describes FMEA and field data feedback as a separate entity. It can be argued that without that availability of field failure data feedback potential failure mode can be overlooked, and as a result failure is built into the product jeopardizing the quality and reliability of the product. FMEA has been discussed in the literature as a technique for the identification and analysis of potential failures that can occur in a product. Existing literature on field feedback has hardly focused on the use of

FMEA as a tool for reliability improvement. Although literature acknowledges that field data serves as input into FMEA, there is lack of emphasis on how to integrate field data into FMEA so that it is automatically generated when required. Also the integration of field data into FMEA would give designers a better understanding of product failure through the use of historic data. There appears to be little research carried out on improving the feedback process structure and the quality of field data recorded by service engineers. Doing so will ensure that quality information is captured, analysed and delivered to the proper stakeholders on time and in an appropriate format.

The novelty of this research work is restated in light of the views emerging from the literature reviewed. A gap has emerged from existing literature which indicated that more emphasis has been made on the technical aspect of field feedback and not enough focus on the management of the process. This research would explore the holistic view of the feedback process within a heating technology industrial setting. It would focus on identifying antecedents for the management of an effective service-to-design feedback process.

2.14 Conclusion

The literature review chapter has presented an extensive review of the literature concerning product field failure feedback from service-to-design in the context of product development for the purpose of quality and reliability improvement of existing and new product generations. The overall review of literature is to gain an understanding of the domain area and identify gaps in existing research and determine research focus.

It is evident from the literature that the occurrence of failures in product in use by customers is inevitable. Product development must be able to cope with the requirements posed by the business drivers. One of the ways of achieving this is to be able to identify problems and risks before they occur. In order to reduce risks in product development, manufacturers need to have access to reliable information about product performance in the field. Field data enables the product development team to learn from the past and anticipate reliability risks for future products, so that these potential failures or risks are eliminated from both existing and new product generations. An approach used for achieving this is the through the use of FMEA. Service engineers are required to capture useful field data that is relevant for use by designers in making decisions on design changes. Field data must be available at the right time especially during early phases of product development where meaningful and cost effective impact can be made on improving the products. This, however, requires the intensive collaborative effort of a cross-functional team. The field failure feedback is a process that enables designers to learn from product performance in the field. The literature indicated that there should be a closed feedback loop from service-to-design in order to achieve an effective improvement in product quality and reliability, hereby assuring product quality that satisfies customer expectations.

Product field failure data is the major form of performance feedback on the ability of a product to perform its intended function when used by the customer. Having access to accurate failure data is important because it enables design engineers to

analyse the overall product performance in the field for the purposes of future product innovation. Results generated from the failure analysis can be used to prevent similar failures from reoccurring in future products, which of course contributes to improvements in product quality and reliability and ultimately aims to achieve greater customer satisfaction. Although field data provides valuable information on product performance in the field, this information is limited. In addition the available field data is hardly suitable for product quality improvement and finally the literature on field failure feedback is mainly confined to the electronic industry and lacks emphasis on the organisation and management of the field feedback process.

To conclude, the literature review has provided a clear understanding of the field failure feedback process in the context of product improvement. It has highlighted existing research on this subject matter and identified gaps in existing research. This review of literature would be used as background knowledge for further exploration of the antecedents of an effective service-to-design feedback process. The theories identified in the literature would be applied to the empirical investigation (see chapter 4) in order to propose a framework for an effective service-to-design feedback process (See chapter 5).

CHAPTER 3: RESEARCH AIM AND PROGRAMME

The previous chapter on literature review identified the gaps that have led to the need for research on effective management of the feedback process from service-to-design. The purpose of this chapter is to define and select a suitable methodology for addressing the research problem. This chapter discusses the different research approaches available for research enquiry and presents the research methodology designed and used in this research investigation.

3.1 Research methodology: key concepts and theoretical considerations

Research is a systematic process of enquiry that focuses on a defined subject area that involves collecting, analysing and interpreting information in order to achieve greater understanding of a phenomenon (Leedy and Ormrod, 2005). Research in academic disciplines is often categorised into two distinct types, pure and applied research. Pure research is usually theoretical work undertaken to acquire new information and contributes to advancement of knowledge. Whilst applied research is work undertaken primarily to apply its finding to solve a specific problem. Blaikie (2000) stated that research is often a blend of both pure and applied types.

There are many research design options available to a researcher for conducting a research inquiry in a defined domain. As a result, there is often no one right or set way of conducting a piece of research. Therefore, the researcher is faced with the challenge of choosing the most appropriate methodology to suit the research enquiry and questions. Many of the choices available to a researcher are attributed to a particular philosophical position.

When designing a research enquiry it is important to understand the theoretical paradigms which establish the general approach to the research. The term paradigm refers to the scientific practise based on a researcher's particular philosophy and assumptions about the world and how research should be conducted. In order to design a methodology to best suit this research investigation the following three theoretical concepts were considered and discussed in details in the following sections:

- Research Philosophy
- Research Purpose
- Research Strategy

3.1.1 Research philosophy

Research philosophy relates to knowledge and its development in a particular academic field or discipline. Easterby-Smith *et al.*, (2002) states that a philosophical perspective is useful in clarifying decisions about research designs by considering the kind of evidence that might be required, how to gather and interpret it in a way that provides answers to the questions being investigated in the research study. He further emphasised its importance by stating that philosophical paradigms are fundamental to research design and failure to consider them can seriously affect the

quality of the research. A number of authors argue that the research philosophy adopted by a researcher contains assumptions about the researchers world view (Easterby-Smith *et al.*, 2002; Yin, 1994; Saunders *et al.*, 2007). Therefore it is important to understand the research paradigms as they will have an impact on the overall research design.

There are two main contrasting paradigms upon which research methods are based; they are positivist and phenomenological paradigm. The positivist paradigm relates to observing social reality which can be measured using a scientific approach using objective methods which involves thorough testing and observation rather than being inferred subjectively through experience or intuition. Under a positivist paradigm, theory is deduced through explanation which seeks to establish causal relationships between variables (Hussey & Hussey, 1997). Positivists tend to adopt a deductive and quantitative approach to a research investigation.

In contrast, phenomenological paradigm refers to the way in which researchers make sense of the world around them. Reality from a phenomenological perspective is socially constructed, subjective and difficult to measure. Here the focus is on understanding what is happening and why, appreciating the different constructions and meanings people give to their experience rather than measurement of social phenomenon. In this paradigm an inductive approach is used for developing theories and seeks to describe and explore research investigation from a qualitative perspective. Table 3-1 presents a comparison of the key features of both philosophical perspectives.

Table 3-1: Comparison of positivism and phenomenologist perspective (adapted from Easterby-Smith et al., 2002, Hussey & Hussey, 1997)

Characteristics	Positivist	Phenomenologist
Observer	<ul style="list-style-type: none"> Must be independent 	<ul style="list-style-type: none"> Observer is part of what is observed.
Research progresses through	<ul style="list-style-type: none"> Hypotheses testing and deductions 	<ul style="list-style-type: none"> Data gathering, generating theories and induction
Concepts	<ul style="list-style-type: none"> Need to be operationalised, so that it can be measured 	<ul style="list-style-type: none"> Should incorporate stakeholders perspectives
Unit of analysis	<ul style="list-style-type: none"> Reduce to simplest terms 	<ul style="list-style-type: none"> May include the complexity of whole situations
Sampling	<ul style="list-style-type: none"> Requires large numbers selected randomly 	<ul style="list-style-type: none"> Small in depth samples.
Generalisation	<ul style="list-style-type: none"> Through statistical probability 	<ul style="list-style-type: none"> Through theoretical abstraction
Validity	<ul style="list-style-type: none"> Low 	<ul style="list-style-type: none"> High
Reliability	<ul style="list-style-type: none"> High 	<ul style="list-style-type: none"> Low

3.1.2 Deductive and Inductive

In deductive research, a hypothesis is necessary. It is based on the findings of previous research from the review of literature or from the researcher's previous experience with the subject. The ultimate objective of deductive research is to decide whether to accept or reject the hypothesis as stated. Inductive research goes from the specific to the general whilst deductive research goes from the general to the specific. Due to the nature of inductive and deductive research, it is argued that it is not feasible to undertake both types concurrently. Both deductive and inductively approach are characterised into four main stages as illustrated in figure 3-1. Inductive strategy can be used to pursue an exploratory objective to answer 'what' questions. This would allow the research to describe phenomena and establish regularities.

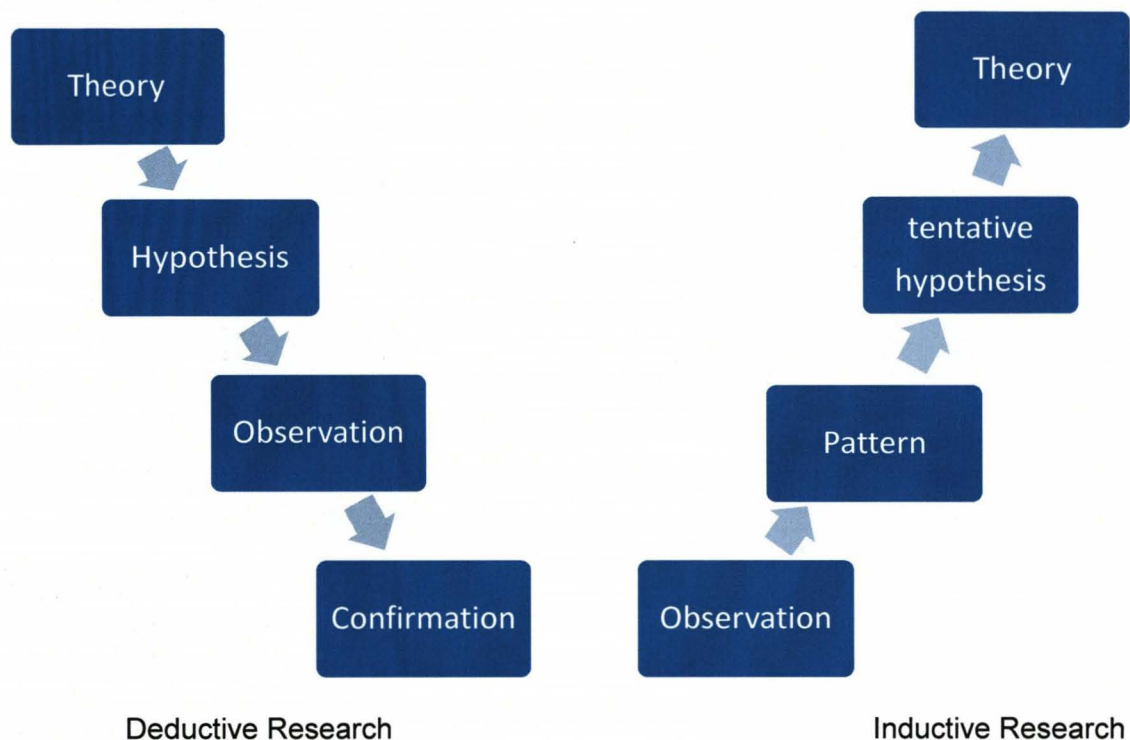


Figure 3-1: Deductive and Inductive research model

3.1.3 Quantitative and Qualitative Research

Research methodologies are often classified into two different types: quantitative and qualitative approach. Both groups of research methods, rather than being methods in their own right. Any specified method of doing research will belong to one or the other. Quantitative research answers questions about relationships among measured variables with the purpose of explaining, predicting and controlling the phenomena. In contrast, qualitative research answers questions about the complex nature of phenomena, with the purpose of describing and understanding the phenomena from the participant's point of view (Leedy & Ormrod, 2005). Although quantitative research methods (descendant of a positivist philosophy) and qualitative methods (descendant of a phenomenologist philosophy) are often seen as opposing views, they are frequently used in conjunction. The purpose of qualitative research is to facilitate taking action in the real world in order to bring about change. In contrast, the purpose of the quantitative approach is to develop causal laws, where data are derived from the use of strict rules and procedures (Robson, 2002). The quantitative approach is deemed as the so-called 'scientific' approach (Robson, 2002) and is characterised by an analytical approach to data that normally involves the numerical analysis of data often generated through questionnaire survey instruments.

The distinctions between quantitative and qualitative data collection techniques are sometimes ambiguous. Although some researchers perceive qualitative and quantitative approaches as incompatible, (Patton, 1990) believes that the skilled researcher can successfully combine approaches. Strauss and Corbin, (1990) and Easterby-Smith *et al.*, (2002) suggested the use of techniques from the same paradigm whenever possible and also to traverse paradigms, but this must be done

with care. Partington (2002), argued that quantitative and qualitative approaches should be viewed as two ends of a continuum instead of viewing them as a discrete either/or options. Therefore the approaches can be used to complement each other. Distinguishing characteristics between both approaches is presented in table 3-2 below.

Table 3-2: Distinguishing characteristics of quantitative and qualitative approaches (adapted from Leedy & Ormrod, 2005)

	Quantitative	Qualitative
Assumption	<ul style="list-style-type: none"> • Usually associated with positivism • One truth • The method is the focus 	<ul style="list-style-type: none"> • Usually associated with phenomenology • Multiple truths • The subject is the focus
Purpose	<ul style="list-style-type: none"> • To Explain and predict • To Confirm and Validate • To test theory 	<ul style="list-style-type: none"> • To describe and explain • To explore and interpret • To build theory
Methods	<ul style="list-style-type: none"> • Representative, large sample • Standardised instruments 	<ul style="list-style-type: none"> • Informative, small sample • Observations, interviews
Reasoning	<ul style="list-style-type: none"> • Deductive Analysis 	<ul style="list-style-type: none"> • Inductive Analysis
Research process	<ul style="list-style-type: none"> • Focused • Known variables • Established guidelines • Static design • Context free 	<ul style="list-style-type: none"> • Holistic • Unknown variables • Flexible guidelines • Emergent design • Context bound
Researchers role	<ul style="list-style-type: none"> • Detached view 	<ul style="list-style-type: none"> • Personal view

3.1.4 Research Philosophy and Methodology Adopted

This section presents a justification for the philosophical and methodological approach adopted in this thesis which is based on their key attributes, strengths and weaknesses and the nature of research problem. This research to a great extent adopted a phenomenological perspective, as it enables a deeper understanding of service-to-design feedback process operations. According to Miles and Huberman (1994) phenomenology explicate the ways people understand, justify, take action and manage their daily situations, these sets of characteristics suggests the suitability of the paradigm for this research, as it attempts to understand the current feedback process from service-to-design, and identify ways of effectively managing the process. As this research does not commence with a predetermined theory, it is not deductive. An inductive approach was adopted and further supported by both qualitative and quantitative approach to elicit further knowledge. The dearth of research on service-to-design field failure feedback process required a need for conducting an in-depth exploratory review of the subject domain. This can be achieved by observing raw data in order to identify patterns and key themes emerging from the data collected which can be further explored to develop theories.

3.1.5 Research Purpose

In considering the research purpose, Robson (2002) argues that in addition to making a contribution to knowledge, the reasons for conducting research are to explore, explain and describe an event or situation. All three categories of research purpose can be adopted in either qualitative or quantitative nature research. See Table 3-3 below for the key characteristics underpinning a research purpose.

Table 3-3: Key characteristics of a research purpose (Robson, 1993; Hussey & Hussey, 1997)

Purpose	Key characteristics
Exploratory	<ul style="list-style-type: none">• Looks for pattern, ideas or hypothesis• To gain insight and familiarity with subject area• To assess existing theories in a new light• Rarely provides conclusive answers to problems but give guidance on future research, if any, to be conducted• Usually qualitative but may also be quantitative
Descriptive	<ul style="list-style-type: none">• Describes phenomena as they exist• To identify and obtain information on the characteristics of a particular problem• May be qualitative and/or quantitative

Explanatory	<ul style="list-style-type: none"> • To understand a phenomena by discovering and measuring causal relations among them • Identifies and possibly control variables in research activities • May be qualitative and/or quantitative
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3.1.6 Research Strategy

Walsh (2001) defined research strategy as methodologies of enquiry that define the methods researchers use to collect data. Research strategies seek to achieve the best procedure for dealing with a research, in particular, for answering the research questions. Saunders *et al.*, (2007) stated that a researcher's choice of strategy is guided by the research question(s) and objectives, and the extent of the existing knowledge and resources available as well as the researcher's philosophical perspectives.

Yin (1994) suggested the following three factors for selecting research strategies, the types of research question, the degree of control that the researcher has over the events and the degree of focus on existing or past event. Table 3-4 presents the relevant situations which each research strategy can be used as suggested by Yin (1994) and the appropriate enquiry of purpose for each strategy.

Table 3-4: Criteria for selecting research strategies (Yin, 2003)

Strategy	Enquiry Purpose	Type of research question	Requires control over events	Focus on current event
Experiment	Explanatory	How, Why	Yes	Yes
Survey	Descriptive	Who, What, where, how many, how much	No	Yes
Archival Analysis	Exploratory	Who, what, Where, How many, How much	No	Yes/No
Case Study	Exploratory	How, Why	No	Yes

Robson (2002) identified the following five research strategies for conducting so called 'real world' research; experiment, non-experiment, case study, action research and grounded theory. Whilst other research strategies exist (Gill & Johnson, 2002),

this research primarily adopts a case study strategy which deploys interviews and questionnaire survey research methods.

Case Study is defined as an empirical inquiry that investigates a contemporary phenomenon within its real life context (Yin, 1994). It focuses on understanding the dynamics present within single settings (Hussey & Hussey, 1997). According to Peshkin (1993), by using a case study the research serves to reveal the nature of certain situations, processes, relationships, systems or people, gain insights about the nature of a particular phenomenon, develop new concepts about the phenomenon and discover existing problems within the phenomenon. Also the research serves to test the validity of certain assumptions, claims, and theories within real-world context; and finally provide a means through which researchers can judge the effectiveness of particular practises. This was augmented by a survey strategy that involved the collection of information from a large population in order to understand the population. The survey method usually employs the use of a standardised questionnaire and/or a structured interview, with standard questions (Robson, 1993).

3.1.7 Research purpose and strategy adopted

There is a dearth of academic literature concerning how feedback from service-to-design tends to support product improvement. This research being a 'what' question requires an inductive strategy. 'What' questions enables the researcher to make appropriate observations or measurements. Therefore, the primary purpose of this study was to further explore this phenomenon and so an exploratory approach was adopted, to derive new insight and understand current practise and develop theory inductively from the data collected. The flexibility offered by exploratory research allows the focus of the research to be broad initially and then progressively narrows as the research ensues, allowing for greater adaptability. There is also a descriptive element in the research design that provides accurate descriptions of situations and events as well as further evaluations and conclusions from the data gathered.

A descriptive method is used because the research portrays an accurate report of persons, process and situations. As a result, this research study has deployed a multiple research purpose. In addition a combination of case study and survey strategy is adopted for this research. Both strategies would be useful in establishing different views of phenomena. The rationales for selecting a survey strategy is that the statistical data produced from the survey would enable the researcher to make data more visible and understandable to readers.

Yin (1994) asserted that case studies are considered as the ideal method for answering 'how' and 'why' questions, and especially when the researcher has little control over events, and when the focus is on a contemporary phenomenon within some real-life context. As this set of conditions applies to this research, the case study is chosen as the most appropriate strategy for this research. According to (Gummesson, 1991), case study provides the opportunity for a holistic view of a process.

3.1.8 Case Study and Survey Strategy

Gill and Johnson (1997) asserted that case study strategy is highly relevant if there is a need to combine research with practise in the real world. In addition Voss *et al.*, (2002) states that case study strategy is good not only at investigating 'how and why' questions, but also particularly suitable for developing, testing and refining theory.

A single case study approach was adopted by the researcher to gain an in-depth understanding of the feedback process from service engineers to designers for product improvement. However multiple unit of analysis was embedded into the case study. According to Yin (2003) it is possible to embed more than one unit of analysis within a case study. The use of multiple sources of evidence within this case study would allow triangulation of data sources and reduce the effect of bias in the findings (Robson, 2002; Yin, 1994). The case study approach is used because of the dearth of information on service-to-design feedback process. It would enable the investigation into the "how and why" of the feedback process operation and its lack of effectiveness. By using a case study strategy, this research serves to describe the current feedback process, its limitations and the need for improvements, and thereby further develop theory from its findings. A case study provides a better understanding of individual cases by seeing things within the context of the whole.

The rationale for adopting a case study approach is its ability to support research questions through variety of evidence. It is also useful for understanding and exploring emerging processes and building theory (Easterby-Smith *et al.*, 2002, Yin, 2003, Gill and Johnson, 1991). Yin (2003) suggests that a case study can help reduce bias by not being restricted to one source of data and consists of a variety of sources such as interviews, observation, documents, artefacts and archival records attaining for triangulation. Other reasons for selecting a case study strategy include its strong academic credibility and thoroughness for use in research investigations of this type published in international and peer review literatures. As a result of all these reasons, a case study approach will be used in the empirical investigation and the validation of the proposed conceptual framework. The diagram in figure 3-3 illustrates the overall process of the empirical investigation case study design.

Surveys entail gathering information from a segment of the larger population to understand something about that population. Robson (2002) offers three main methods for collecting survey data: self completion questionnaire; face-to-face interview and telephone interview. This method usually employs the use of a standardised questionnaire or / and a structured interview, with standard questions (Robson, 1993).

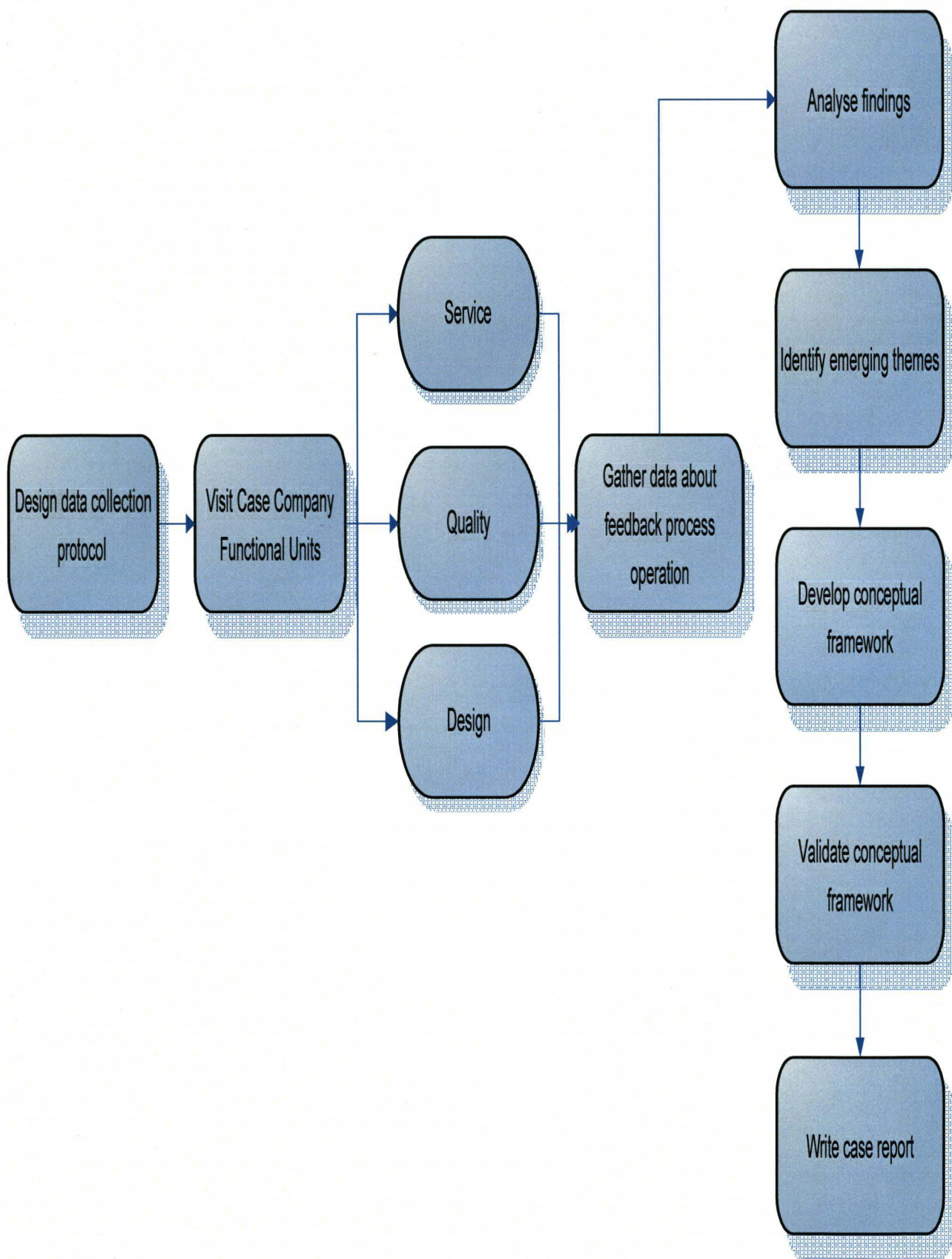


Figure 3-2: Case study overall process modified from Yin (2003)

3.2 The Research Process

The term methodology, in its broader sense, refers to the complete research process and describes the detailed approach to data collection and its analysis. According to Leedy & Ormrod (2005), the research methodology directs the research study, dictates how data are acquired, arranges them in logical relationships, sets up an approach for refining and synthesizing the raw data, and contrives an approach so that the meanings in the data become clear and conclusions can be derived to contribute to knowledge production. Research process is often presented in literature as a multi-stage process that is undertaken by a researcher in order to complete a research study. Example of such stages include formulating and clarifying a topic, establishing research questions, aim and objectives, reviewing the literature, research design, data collection, data analysis, and interpretation write up. Figure 3-2 below illustrates the research process used in this research study. Saunders *et al.*, (2007) argues that the research process is often portrayed as being rational and straightforward yet in reality it is an iterative process which often requires revisiting each stage and refining one's ideas about research design and implementation.

Each of the research objectives are accomplished in the different phases of the research programme and presented as separate chapters in this thesis structure.

The focus of the first phase of the research is to carry out an investigation on existing research on service feedback process to product development process in particular the design function for facilitating product quality and reliability improvement. This phase led to the identification of gaps in existing research as presented in the previous literature review chapter.

The emerged themes as well as the identified weaknesses in existing literature is then used for designing interview questionnaires for exploring the actual service-to-design feedback process operation in practise within the sponsoring company in the second phase. The second phase involved conducting an empirical investigation using a single in-depth case study to explore service-to-design feedback process operation in practise within an industrial setting, in other to acquire the requirements for an effective field feedback process.

The emerged theoretical concepts were developed through a series of inductive iterations based on both literature reviews and empirical case study. The research extensively used triangulation using questionnaires, company documentations, interviews reports, qualitative and quantitative data to identify converging lines of investigation and ethnographic methods to enhance the validity and reliability of the research outcomes.

The outcome of this research is expected to enhance a better understanding of the need for service-to-design feedback and how the process should be managed. This in turn will enhance the overall effectiveness of the process for the purpose of supporting product innovation.

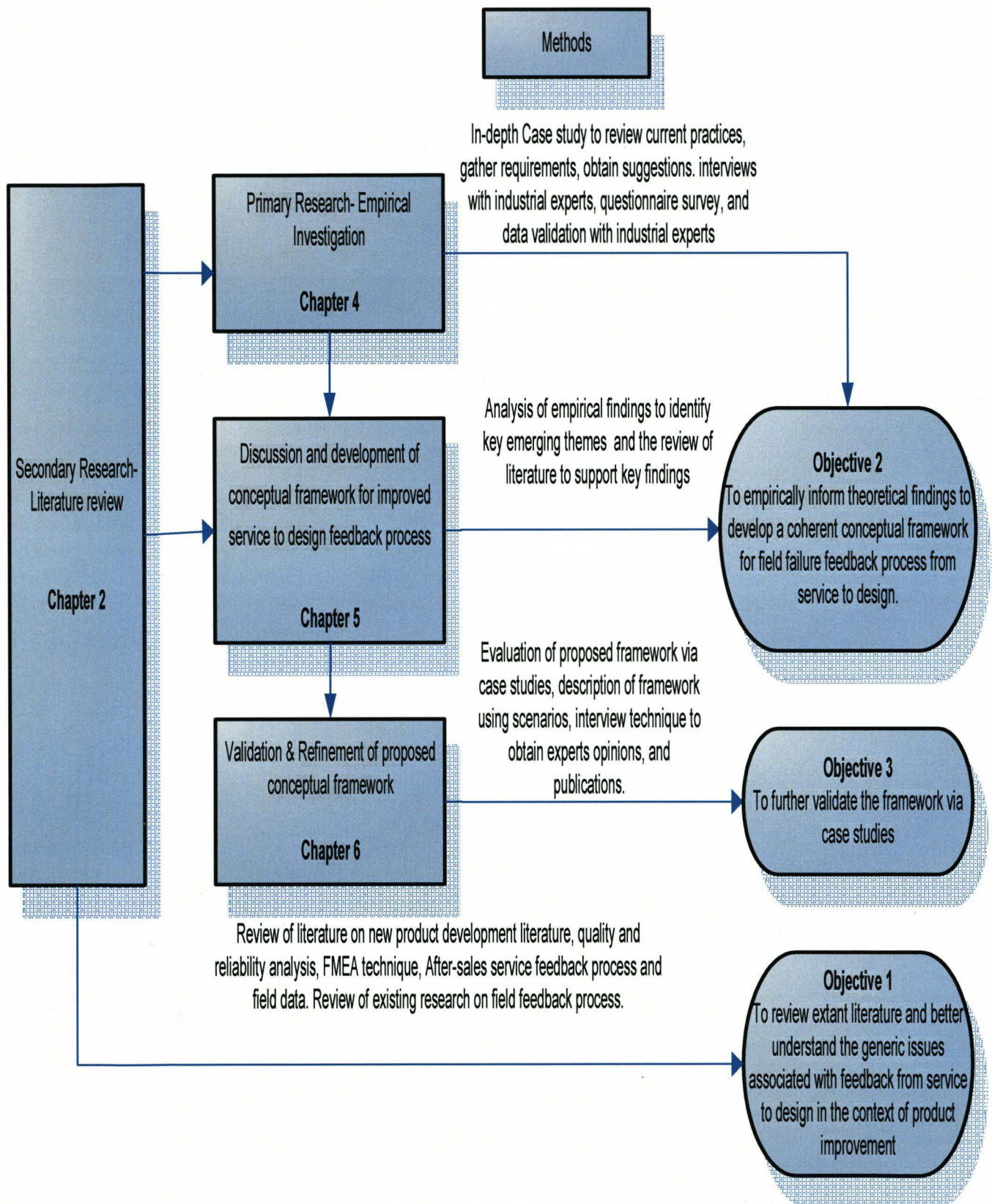


Figure 3-3: Research Process

3.2.1 Selection of unit of analysis

The three units of analysis used for the empirical study were selected because they are the key stakeholders of the feedback process. Table 3-5 illustrates a table of the unit of analysis. The unit of analysis used in this research investigation was selected based on the following criteria:

- A function within product development process
- The feedback process is key to its functional activities
- Contributes to different aspects of the feedback process

Table 3-5: Profile of case company selected unit of analysis

Case Company	Vaillant Group		
Size	350+		300+
	R&D		
Unit of Analysis	Quality	Design	Service
Responsibilities	<ul style="list-style-type: none"> • Failure prevention • Failure analysis • R-prognosis • FMEA • Defining preventive actions & quality targets • Part risk assessment 	<ul style="list-style-type: none"> • Design/development • Construction • Identification of parts to be used • Parts Phase IN/Phase OUT • Defining system elements and its functions 	<ul style="list-style-type: none"> • Service, maintenance • Spare part • Customer complaint
Access via	<ul style="list-style-type: none"> • Quality Planning Engineer 	<ul style="list-style-type: none"> • Product manager 	<ul style="list-style-type: none"> • Service quality manager
Participating Team	<ul style="list-style-type: none"> • Quality Planning • CPI 	<ul style="list-style-type: none"> • CoC hydraulics • Design constructions/development 	<ul style="list-style-type: none"> • Regional service manager • Field engineers • Service quality manager

3.3 Data collection and Analysis

As part of this case study research investigation, it was important to consider data sources that are most appropriate to address the research questions in order to achieve the research objectives. Yin (1994) identified six main sources, which are documents, archival records, interviews, direct observations, participant observation and physical artefacts. See Table 3-6 below, for the strengths and weaknesses of the various data collection techniques.

Table 3-6: strength and weaknesses of the data collection techniques (Yin, 2003)

Methods	Strengths	Weaknesses
Documentation	<ul style="list-style-type: none"> • Stable- it can be reviewed repeatedly. • Contains exact details of an event • Multiple source can facilitate data triangulation • Data can be tracked over a long period of time 	<ul style="list-style-type: none"> • Irretrievability can be low • Biased selectivity, if collection is incomplete • Access may be deliberately blocked • Reporting bias reflects bias of author
Interviews	<ul style="list-style-type: none"> • Targeted-focuses directly on case topic • Insightful-provides perceived causal inferences 	<ul style="list-style-type: none"> • Bias due to poorly constructed questions • Response bias • Inaccuracies due to poor recall • Interviewee says what interviewer wants to hear
Questionnaire	<ul style="list-style-type: none"> • Respondent can be quantified for the case analysis • Time efficient for researcher and respondents 	<ul style="list-style-type: none"> • No opportunity for clarification and deeper questions • Data collection depends on respondents goodwill • Quantity of data collected is limited

Direct Observation	<ul style="list-style-type: none"> • Covers event in real time • Covers context of event 	<ul style="list-style-type: none"> • Time consuming • Event may proceed differently because it is being observed
Archival records	<ul style="list-style-type: none"> • Precise and quantitative 	<ul style="list-style-type: none"> • Accessibility due to privacy reasons

The literature review is the secondary data collection technique used in this research and the primary sources of data collection for this study are interviews and questionnaire survey instruments. Where possible other techniques such as observation and company documentation were used to triangulate with the objective of overcoming potential bias and validating the quality and reliability of the data and data sources.

3.3.1 Literature Review

The literature review is often the starting point of a research inquiry. It is a critical and evaluative report on what has been published on a chosen research topic. Its purpose is to summarise, synthesise and analyse the arguments of others. The researcher can describe and analyse the knowledge that exists, gaps that occur in research related to the research study in order to reveal similarities and differences. The purpose of conducting literature review in this research is to gather information on the area under investigation so that researcher can gain knowledge about the subject area. As suggested by Strauss and Corbin (1990), Literature review was conducted (see chapter 2) because of the following reasons:

- To stimulate theoretical sensitivity: by providing concepts and relationships that can be compared to the actual data collected.
- To provide secondary sources of data: to be used perhaps as initial hypotheses testing of the researchers' concepts and ideas.
- To stimulate questions during data gathering and data analysis.
- To direct theoretical sampling – to guide the researcher on how to discover phenomena that are important for theory development.
- To be used as supplementary validation – to justify findings and present augment on it supports or differ from the existing literature.

3.3.2 Interview Survey

In conducting a qualitative research, the interview technique can yield a great deal of rich data. The need to gain insights into the management of product failure feedback process requires the use of an interview because it allows the researcher to obtain facts, opinion about events from first hand sources (Yin,1994).There are different types of interviews such as; face to face, structured, semi-structured, telephone and focused interview. Interviews are essentially conversations between the

researcher/interviewer and their interviewee (research participants) and assume that the participants' perspectives are meaningful and knowledgeable. According to Patton (1990) the quality of information obtained is largely dependent on the interviewer's skills and personality. Easterby-Smith *et al.*, (2002) asserted that interviews are an opportunity for the researcher to probe deeply to uncover new clues, open up new dimensions of a problem and to capture clearly and accurately a problem situation based on personal experience.

3.3.3 Interview design

The objectives of the interviews were:

- To understand the field failure feedback process from service-to-design functions.
- To identify current limitations and barriers to feedback process.
- To explore how the failure data is collected, analysed and utilised.

The literature review identified a number of gaps in the existing body of knowledge. The main issues identified from the literature are the limited research focus on service-to-design field failure feedback process management and the problems with quality of failure data captured in the field. The literature influenced the areas to focus on in the research, no existing model of questions from the literature were adopted to formulate questions. The interview questions were formulated by the researcher to relate to the emerged gaps identified from the literature as well as the research problems and objectives it aims to fulfil. The interview questions were developed using the "what" and "How" context which shows the exploratory nature of the questions due to the dearth of research in the subject area. The "how" questions were used with various adjectives to ask detailed information about the subject that is examined.

The criteria considered for creating the questions are relevance, which meant that the questions must be related to the purpose of study and capable of eliciting the data desired by the researcher, the second criteria was to consider the respondent of the interview by ensuring the question is worded in a language or terminology that is understandable by the interview participants and finally the ease of response is equally important, this meant that questions must be relatively easy to answer by the interviewees.

The interview questions were developed in an open ended format in order to elicit the kind of information required by the researcher. The interview questions consist of four parts: general information about the participant role and relationship with the field failure feedback process. b) the feedback process operation c) the FMEA technique and d) the failure data recorded from the field. The interview questions were designed for service, design and quality engineers who are the main stakeholders of the product-in-use failure feedback process. The questions were piloted with Cranfield faculty and PhD community. Figure 3-4 below illustrates the interview design approach taken by the researcher.

Feedbacks from the piloted questions were used to modify the interview questions.

A final version of the interview questions were accompanied by a covering letter, see appendix (I), which was sent to each research participant in advance of the face-to-face interview. The covering letter explained the purpose of the interview, provided the interview questions, what the researcher aimed to achieve from it, assured confidentiality and anonymity, stated the amount of time required for the meeting and encouraged the participant to bring any supporting company documents or other artefacts to aid their responses during the interview process. In conducting this research investigation, data triangulation and investigator triangulation strategies have been exploited to address bias in the data collection and interpretation.

3.3.4 Interview Participant selection

The research presented findings from the literature with the industrial project manager and discussed plans for the interviews to be conducted. Together with the project manager the researcher created criteria for participant in the interview which is:

- Participant must be from the quality, service and design function, as they are the three main stakeholders of the product failure feedback process
- Must be actively involved in the feedback process either as a contributor to the process or the user of the information produced by the process
- Participant must have some understanding of the feedback process
- Able to communicate reasonably both verbally and orally in English as most of the participants are based in the company headquarter in Germany where the official language within the company is German and the researcher is only able to communicate in English.

Once these criteria were set the industrial project manager helped the researcher in selecting appropriate interviewees that meets all the set requirements. Table 3-7, illustrate shows a list of job roles of the interviewees.

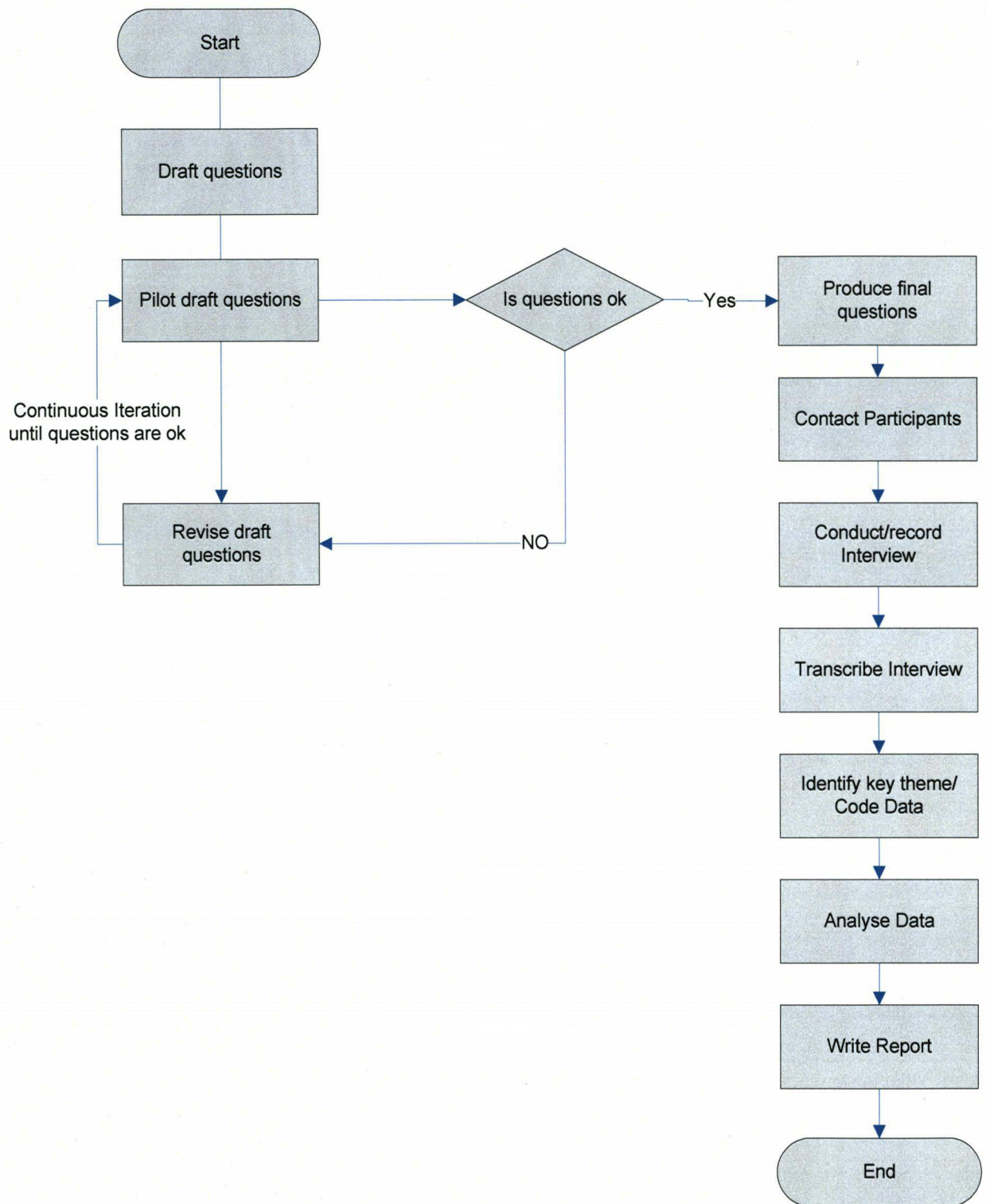


Figure 3-4: Interview Survey approach

3.3.5 Interview Implementation

The interview process began with a brief introduction, whereby the interviewer introduced herself and the purpose of the interview, assured confidentiality, asked for permission to audio tape record and make detailed notes. The interview commenced

and the participants were asked to describe their role within the company; this was to establish a good rapport at the outset of the interview. A face to face interview was conducted as this provided a higher richness of communication than telephone interview (Gillham, 2001a) however; face to face interview can be very expensive as it required a lot of travelling to clients' site.

A semi-structured interview was conducted which allowed the interviewer to use probing techniques to obtain further response from the participants. A semi-structured interview method was adopted because it allows the flexibility to ask questions about emerging issues during the investigation, whilst keeping the researcher focused with the research boundary. Easterby-Smith *et al.*, (2002) argues that interviews are appropriate methods for understanding the constructs an interviewee uses as a basis for his/her opinions and beliefs about a particular situation, when the researcher wishes to develop an understanding of the respondent's 'world' so that he could influence it.

The main role the research during the interviews, apart from keeping the process in control and guiding it to productive areas, was to listen, take note and make sure that each of the interviewees had an opportunity to express themselves. Patton (1987) argues that the fundamental principle of qualitative interviewing is to provide a framework within which respondents can express their own understandings in their own terms. Table 3-8 illustrates the number of interviews conducted, the number of hours taken and the number of transcript pages generated. Interviews were conducted with quality, service and design engineers, however it was difficult to gain access to service engineers, in total only four personnel was interviewed, this a relatively small sample when compared to the number of personnel interviewed from the design function. This is because service engineers are dispersed around the country and often work to target. It is difficult for them to schedule a meeting within working hours. In this circumstance a questionnaire survey seemed appropriate and would be discussed in section 3.3.9. At the initial stage of the empirical study only the interviews were used, as the research progressed into the in-depth case study both interviews and questionnaire survey were conducted in parallel. This facilitated the triangulation of data collected.

Simultaneously, company documentation was surveyed in order to triangulate, and thus substantiate the interview data. The questionnaire questions were similar but did not duplicate the interview questions. Overall the interview took 60mins on average. Data from the interviews were triangulated through multiple sources, in order to improve the research validity. Furthermore, data triangulation helps to present an accurate picture of events. The researcher believes that each interview conducted could bring diverse perspectives on the same questions. All the interviews were fully transcribed and ready for the analysis of the data.

Table 3-7: Illustrating the broad range of experts interviewed

Role	No of interviewees	Department	Location
Innovation engineer construction/Design-condensing boiler	2	Design	Germany
Innovation engineer construction/Design-non condensing boiler	2	Design	Germany
Project leader Continuous Product Improvement	2	Quality	UK, Germany
Innovation engineer construction/Design	1	Design	Germany
Project leader Innovation Thermal	1	Design	Germany
Team manager Test department	1	Design	Germany
Innovation engineer development-Hydraulics	1	Design	Germany
Innovation engineer construction/ Design-Hydraulics	1	Design	Germany
R& D Quality Planning	3	Quality	UK, Germany
Field Service Engineer	3	Service	UK
Service Quality Manager	1	Service	UK

Table 3-8: Statistical figures of interviews conducted

No of Interviews	No of Hours	No of Transcript pages
19	38	150

3.3.6 Data analysis of interview data

The data analysis strategy adopted for this research study is based on the qualitative methods of Miles and Huberman (1994). An in-depth analysis of the interviews involved transcribing the tape recorded qualitative data, identifying emerging themes and assigning analysis codes to assist in the interpretation and detailed analysis of

the data. Strauss & Corbin (1998) stated that all field notes, transcripts and other material should be coded and the coding system should be refined as the data collection proceeds. The codes are then integrated comparatively to identify differences and interrelationships. Easterby-Smith (1991) suggested seven stages to analysis which include 1) Familiarisation 2) Reflection, 3) Conceptualisation, 4) cataloguing concepts, 5) Coding, 6) linking, and 7) re-evaluation. However, the central process highlighted in the analysis phase is coding (Strauss and Corbin, 1990). Coding represents the process which data are broken-down, conceptualised and put back together in new ways.

3.3.7 Coding

Coding is the process of combing the data for themes, ideas and categories and then marking similar passages of text with a code label so that they can easily be retrieved at a later stage for further comparison and analysis. To codify the data collected, a considerable amount of time was spent to transcribe the interview data (see appendix II for an example of the data transcript), reading and becoming familiar with the data in order to identify main emerging themes, categories and sub categories. The three main topic areas identified were allocated a code. For example, data about the feedback process was coded to – FBP, and data concerning field failure data into FFD. Sub- categories were preceded with higher level codes to identify data links. The codes are given a meaningful name that gives an indication of the idea or concept that underpins the theme or category.

Whilst reading the transcripts, the researcher recorded the level of emphasis placed on each categorisation using a different colours coding system. Table 3-9 below presents an example of the data analysis coding sheet and the level of details concerning a particular category. The first column indicates the code number and theme, the second column indicates actual quotations in relation to the corresponding theme and the alphabet A-L represents the respondent. The circle under each respondent indicates the level of detail and emphasis each respondent made in relation to each corresponding theme. The clear circle indicates light detail and emphasis, the half painted circle indicates moderate details and emphasis and the fully painted circle indicates heavy elaboration. See appendix (III) for some example of data coding categories. Each interview transcript was given a letter code, which is related to the research participant and kept in a separate document for purposes of confidentiality, anonymity and ease of subsequent cross referencing (See appendix IV, for example of interview transcript). The coding structure was further refined and clustered into key themes to demonstrate relationships in the data.

Table 3-9: Examples of the data analysis coding with twelve interviewees

		A	B	C	D	E	F	G	H	I	J	K	L
Codes	Emerging Key Themes and sub-themes												
6 FFD benefits	Field failure data benefits to product design												
6.1 Failure Modes	Highlights possible failure modes				☐	○						☐	☐
6.2 Improved Design	Improve product design using outcome of failure analysis	●	●	☐		●				☐	●		
6.3 Lesson Learnt	Use experience of previous failure of similar product	☐											
6.4 Solution Implementation	Implement solutions of previous failures in new project	●	●			●				○	☐		
6.5 Interrelationship	Link field failure data to occurrence in fmea	●											
6.6 CPI	Helps with continuous product improvement				☐							●	●
6.7 Feedback	Provide feedback					☐						●	●
6.7 Feedforward	Educate service engineers on use of field data											☐	☐

3.3.8 Questionnaire Survey

Questionnaires are usually considered to be one of the most efficient data collection techniques and widely used to compliment other methods in particular interviews. A questionnaire survey is a means of gathering information about a particular population by sampling some of its members, usually through a system of standardized questions. Surveys can be conducted by mail, telephone, personal interview, or Internet. They can be administered either to individuals or groups. The primary purpose of a survey is to elicit information which, after evaluation, results in a profile or statistical characterization of the population sampled. Robson, (2002) suggested eight steps to be taken as a data collection method, they are:

- Development of research questions
- Study design and initial draft of questionnaire
- Informal testing of draft questionnaire
- Revise draft questionnaire
- Pre-test revised draft using interviews
- Re-Correct questionnaire
- Distribute questionnaire and collect answers
- Analyse data

3.3.9 Sources of the questionnaire survey

The survey aimed at evaluating the findings from the literature as well as findings from the initial industrial exploratory study. Both sources provided information that needed further

exploration. Outcomes of these two sources were used in developing the questions for the questionnaire survey.

3.3.10 Sampling

The target audience for the questionnaire survey are same as the interview survey which consists of personnel from quality, design and service functions, with more focus on the service function because of the difficulty in gaining access to the service engineer for interview.

3.3.11 Questionnaire Survey Design

A structured questionnaire was designed as a survey instrument to collect data from a sample of design, quality and service engineers. The use of the survey method complimented the interviews and provided the researcher with a broader and deeper spectrum of understanding of a range of issues. The literature review indicated that product-in-use failure is important for making product quality and reliability improvement at the design stage of product development. Hence there is a need to manage this service-to-design feedback process to support product improvement. The aim of the survey questionnaire was to identify problems with existing feedback process.

The contact persons within organisation were approached to discuss the intention of conducting a questionnaire survey. The researcher discussed the type of participant required and the need for contact names, email or telephone number of personnel within the specified functions. The quality planning manager (main contact from R&D) organised a list of participant from both the quality and design functions that best suit the set criteria, whilst the service quality manager (main contact from service division) informed the service administrator to comply a list of service engineers addresses so that the questionnaire can be posted to them.

The questionnaire survey was ideal for eliciting information from service engineers because unlike the design and quality engineers, they are dispersed across the country and work to a daily target. The questionnaire survey provides an efficient and cost effective way for obtaining answers to the research question based on service engineers' perspective. The use of questionnaire would also provide more representative sample size of information obtained from service engineers. Due to their time constraint it would be challenging for the researcher to conduct a face-to-face interview with a significant number of participant from the field service role.

A good questionnaire should provide a valid measure of the research enquiry, obtain the co-operation of respondents and elicit accurate information. The design process for the questionnaire survey ensured respondents could easily understand the questions and were able to interpret the questions as intended by the researcher. Therefore questions were worded using familiar terminologies in a simple and precise manner, to reduce the potential for misinterpretation. The researcher adopted the proven technique of Likert scaling which consists; strongly agree, agree, neutral, disagree, and strongly disagree response options. The questionnaire survey was used to obtain the respondents general views, experiences and attitudes towards the field feedback process. Figure 3-5 below illustrates the questionnaire design approach taken.

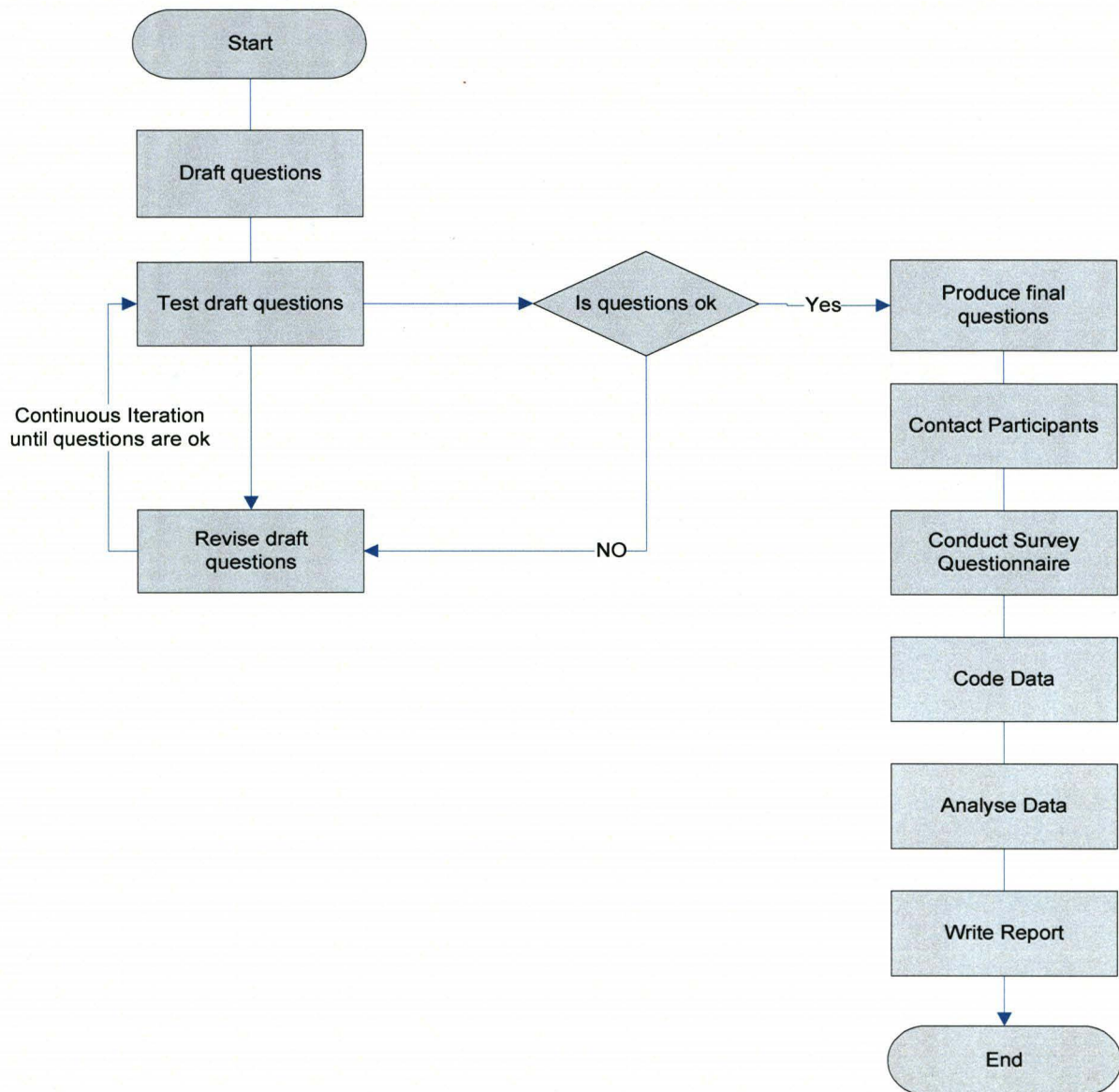


Figure 3-5: Survey Questionnaire design approach

In designing the questionnaire survey, questions were drafted to relate to the research questions and the underpinning literature. According to Frazer and Lawley (2000) process of questionnaire design this requires determining the information to be collected. The questions required in this research is the limitations of existing feedback process and the key factors for managing service-to-design field feedback, Draft questions were then piloted and refined in collaboration with the Cranfield faculty and PhD community, who had knowledge of the research subject area, in order to obtain their view on the structure of the questions. This pilot test allowed the researcher to sanitize the survey items and rectify any potential deficiency. Minor adjustments were made on the basis of specific suggestions. The final questionnaire addressed common themes with some sets of questions being specific to design quality and service engineers respectively. Figure 3-6 below illustrates some examples of the questions designed.

1. The product field failure data reporting worksheet (mop-mis) captures appropriate information about product failure

Strongly agree Agree Neutral Disagree Strongly disagree

2. The design of the service field worksheet (mop-mis) restrict the level of detail that can be recorded about the product failure

Strongly agree Agree Neutral Disagree Strongly disagree

3. Service engineers are aware that the product field failure data captured is done for the purposes of product improvement

Strongly agree Agree Neutral Disagree Strongly disagree

4. Product failure data gathered from the field is of sufficient detail for the purposes of product improvement

Strongly agree Agree Neutral Disagree Strongly disagree

Figure 3-6: Examples of questionnaire questions

3.3.12 Questionnaire Survey Implementation

The questionnaires were accompanied with a covering letter, centrally administered by the researcher and the company's contact in two different R&D sites of the collaborating company, one in Germany and the other in UK. The covering letter stated the aim and importance of the survey, informed on the time duration required to fill out the survey, the generic themes addressed by the questionnaire and assured the confidentiality of the participant's response. The administration of the questionnaire included both face-to-face and postal delivery. See appendix (IV) for the complete questionnaire. From the 99 questionnaires administered to design, quality and service engineers, 41 questionnaires were completed and returned, providing a response rate of 41.4%. Follow up reminders were sent to the company contact in order to increase the response rate. A complete table of responses can be seen in appendix (V). The break down includes the following:

- Returns from service- 13
- Returns from Design & Quality- 28

Questionnaires were also conducted in parallel with the interview survey. At the end of every interview session with each design, service and quality engineers, they were asked to fill out the questionnaire. This also triangulates the responses given in the interview as some of the questionnaire questions are similar to that of the interview. Conducting the interview and question in parallel also saves time and effort in trying to gain access to the respondent. The questionnaires were administered by post to other service engineers who were not interviewed. As mention earlier, this is because of the difficulty of scheduling an interview with them due to their time constraint.

3.3.13 Questionnaire survey analysis

The process of analysis was carried out by cross-tabulating the responses to each question items in an excel spreadsheet, therefore presenting the quantitative data from the survey into meaningful information. The data was used to produce a graphical representation of the responses as shown in figure 3.7. Conclusions made from the survey data were based on the percentages of responses to each question and this was used to compliment and augment findings from the interviews.

A complete quantitative analysis of both service and design engineers' questionnaires can be seen in appendix (V).

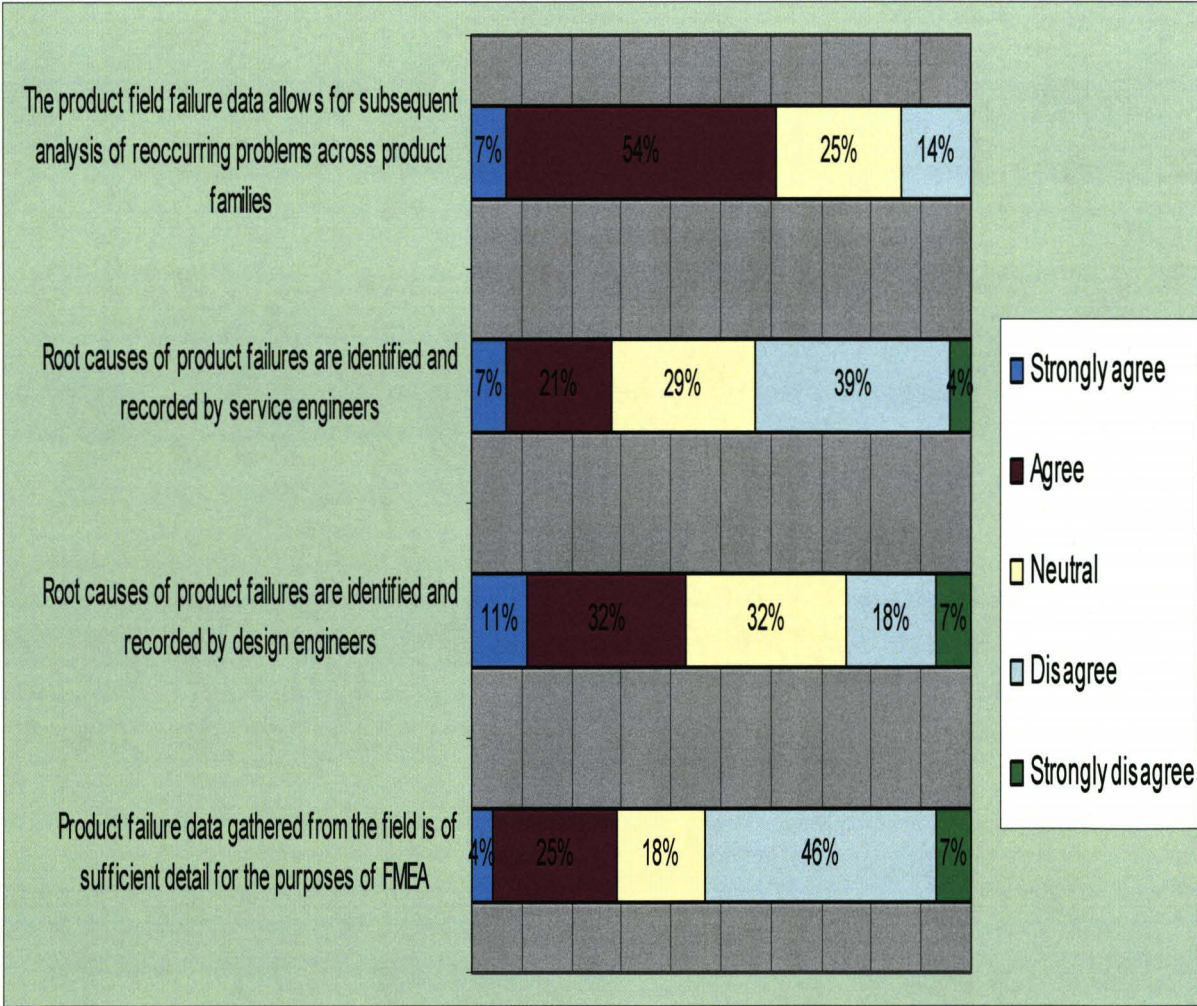


Figure 3-7: Bar chart showing questionnaire response value

3.4 Company documentation

Supporting company documentation that was used in this research investigation included:

- presentation slides on business processes,
- complete product development process documentation which included process flow charts, web materials such as the digital web version of the product development processes,
- excel documentation on field service failure records,
- Computer based training manual on field service engineers PDA application obtained on a compact disc.

3.5 Case study quality and validity

As part of the research process a focus was made on assessing the reliability and validity of the research findings to improve data accuracy by reducing to subject or participant error, Robson (2002). Hussey and Hussey (1997) defined validity as the extent to which the research finding accurately represents what is happening in a situation, showing the true picture of what is being studied from the data collected. Regular contact was maintained with the service quality manager, the CPI manager and the quality planning engineer wherein a rich source of knowledge was provided against which the validity of the research questions, theories and findings and conclusions were discussed. Triangulating the questionnaire responses with other sources such as the interview responses and company documentation addressed bias and threats to validity of information. Patton (1990) argues that documentation of this kind provides a rich source of information.

Yin (1994) identifies three types of validity applicable to exploratory research; they are construct validity, external validity and reliability. Construct validity is described as the degree of certainty one has that the phenomenon has been appropriately measured and studied. External validity is concerned with the extent of confidence one has that the findings can be generalised beyond the immediate case. Reliability concerns the researcher's conviction that the research and its findings are repeatable. According to Silverman (2000) a researcher's ability to show that the methods used were reliable and that the conclusions made are valid are crucial to any social inquiry. With suggestions to the arguments presented above the following measures were utilised to assure quality and reliability of the research:

- Multiple data sources such as interviews, questionnaire survey literature, company documentation and observation were used for triangulation.
- Perspectives of industrial experts on the research findings and framework developed were obtained. Experts include quality, design and service engineers.

- Research results were disseminated in academic peer review journals and conferences.
- Both interview and questionnaire questions were documented. Interviews conducted where recorded, transcribed and analysed using consistent data analysis coding.

3.6 Chapter Summary

This Chapter has reviewed research approaches available for conducting a research study and described the research design chosen for this investigation. Based on this review suitable methodologies were defined and selected for addressing the research problems. Interviews and questionnaire survey instruments were deployed in conducting the research investigation so as to fulfil the set objectives in chapter one of this thesis. Data collected were analysed using data analysis method by Miles and Huberman (1994). In addition, it presented approaches taken to assure the quality and validity of the research enquiry. Figure 3-6 represents the overall approach chosen for the research study.

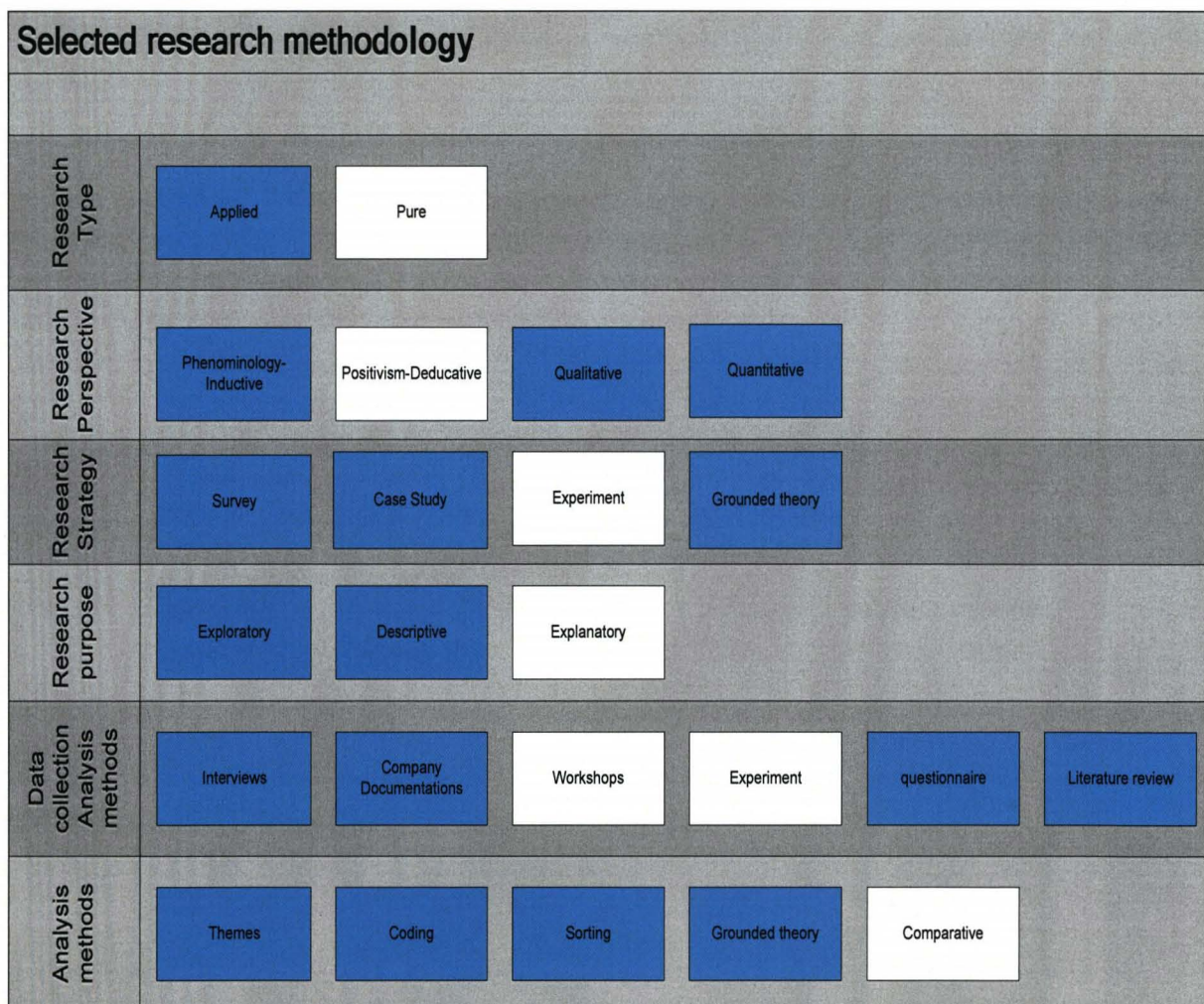


Figure 3-8: Overall approach chosen for the research study

CHAPTER 4: FINDINGS FROM EMPIRICAL INVESTIGATION

The chapter presents the findings from the industrial investigation and stands to fulfil part of the research objectives of this thesis. It examines the case company's current service-to-design feedback process and empirically derives the requirements for a new improved feedback process.

4.1 Introduction

The findings from the literature review demonstrated a dearth of knowledge about what constitutes an effective field failure feedback process. In addition, there is lack of model frameworks and processes for transferring field failure feedback from service into design. This chapter presents the findings of an in-depth empirical case study investigation, which sets out to explore the management and organisational issues associated with product failure feedback to design within the context of new product development. The following section presents a background synopsis to the case company and the findings of the study under the following two main sections:

- Field data
- Feedback process

4.2 Background to case company

The acquisition of Hepworth plc by Vaillant GmbH in 2001 led to the creation of Vaillant Group in 2002. Vaillant Group is a leading global manufacturer of heating, ventilation and air-conditioning technology and also produces household products such as aluminium ladders and work platforms. The empirical study focused on the heating system appliances unit of their business operations which had approximately 10,100 employees, achieved a turnover of around £2 billion and an operating profit of £236 million (Vaillant Group, Annual Report 2007).

Vaillant Group, which will henceforth be referred to in this thesis as the 'case company' owns a series of European boiler brands consisting of Glow-worm in the UK, Saunier Duval in France, AWB in the Netherlands, Protherm in the Czech Republic, Bongianni in Italy, and Vaillant in Germany. The product range includes wall-hung and floor-standing boilers for domestic central heating systems. The core of the Vaillant Group's business is the Heating Technology division, whose £1,952 million sales figure accounts for 98 percent of their total sales. Customers are mostly heating equipment wholesalers and installers such as housing organisations, housing developers and construction firms but not household end-users. The products are manufactured at fourteen sites in six European countries and in China; and sold mainly via its own sales organisations in more than eighty countries.

4.2.1 Product innovation at the case company

The boilers manufactured by the case company comprise six functional modules as illustrated in Figure 4-1.

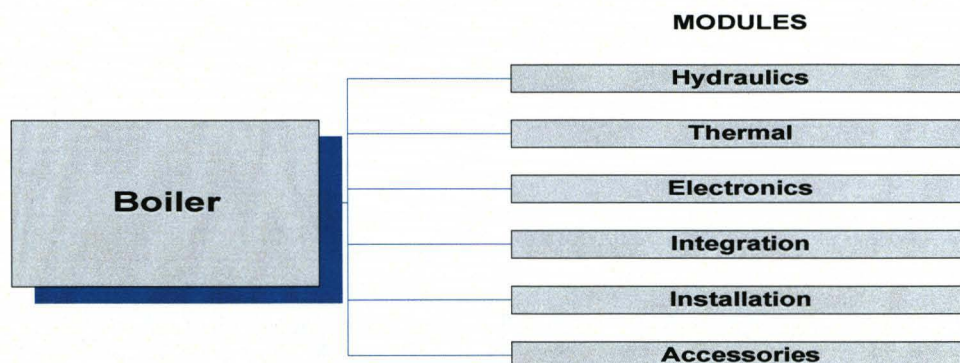


Figure 4-1: Modules of a boiler

The components within the boiler are standardised across different brands, however, the product aesthetics and control systems panel are customised for each market. Each brand has its own separate identity, uniquely positioned and managed by separate sales and marketing teams. The table in 4-1 illustrates the various brands and their contribution to sales.

Table 4-1: Product brands and sales figure

Brand	Market	Sales	Percentage
		£Million	Contribution to sales
	Netherlands	21	1
	Belgium	30	2
	Over 50 countries in Europe, Asia and North Africa.	13	1
	UK	120	8
	Italy	59	4
	24 countries in Europe, Asia and Africa	44	3
	Nantes/France	297	20
	Remscheid/Germany	927	61

(Source: www.vaillantgroup.com)

Product development projects within the Vaillant Group are undertaken by cross functional teams from R&D sites located in Remscheid in Germany, Nantes in France and Belper in UK and Skalica in Slovakia. Vaillant Group's new product development business is represented as a process flow map referred to as the Innovation Process (IP) and used by the R&D during product development. The IP is a step-by-step business process describing all the activities relating to the new product development. It covers the complete lifecycle of a product ranging from the initial concept through to product launch. The IP is a stage-gate product development model that consists of seven phases: product strategy, conception, functional development, detail development, industrialisation – process, industrialisation – launch and review. Each phase in the product development process has a quality gate milestone in which the product reliability and quality is completed and assessed before moving on to the next phase of the product life cycle. At each quality gate all defined criteria (results and targets) must be fulfilled. These quality gates are; Product Strategy (PS), Technical Requirement Specification (TRS), Product/Process Release (PR), Marketing Availability (MA), and End of Project (EOP). A description of each quality gate can be found in Appendix E. The NPD process model depicted in figure 4-2 is similar to generic stage-gate process models portrayed in NPD literatures such as Cooper's stage-gate model. A key similarity between both models is the performance review after each stage of the process.

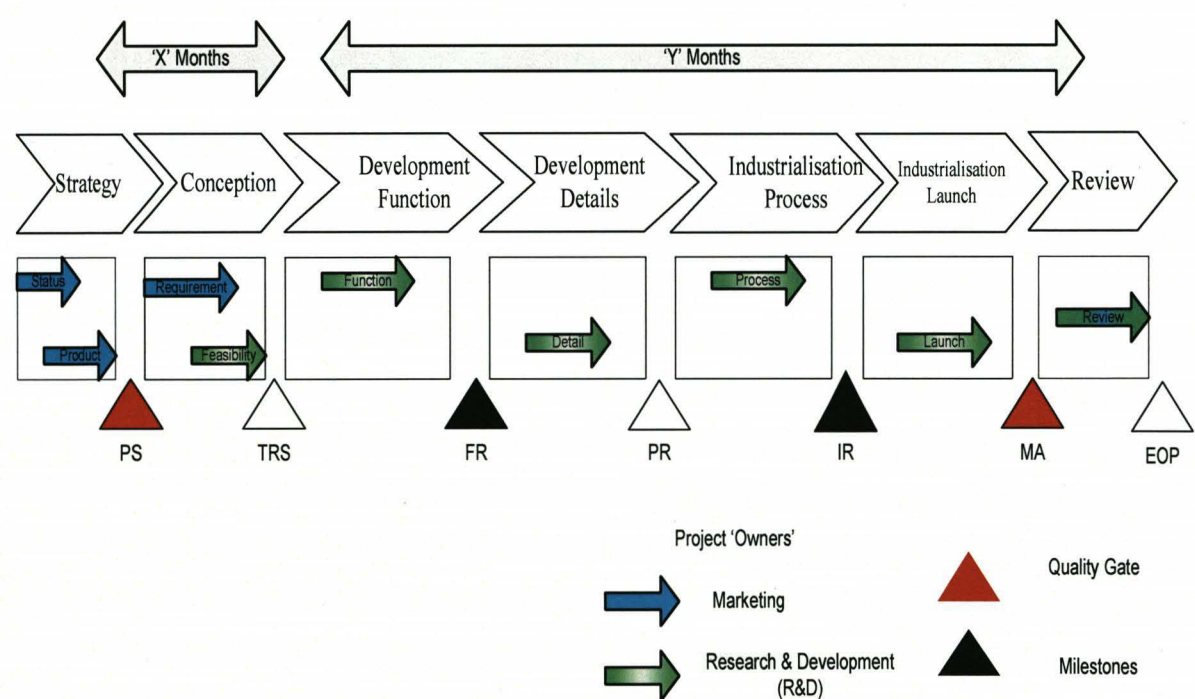


Figure 4-2: Vaillant New Product development Model (adapted from Vaillant Group NPD Process Map)

Quality gates within the Vaillant Group NPD process model are time and content based synchronisation points. At these points all defined criteria must be fulfilled.

These milestones are also time orientated point, at which defined activities must be completed.

The product development project within the Vaillant Group is undertaken by cross functional teams from diverse production units and manufacturing sites within the organisation.

4.2.2 Role of service in case company

New products within the case company are mostly the result of incremental innovation, which involves changes to existing product platforms, to meet customer demands. The new product development projects within the company are driven by manufacturing including environmental compatibility, country of sales' legislation, gas safety requirements, end-user complaints about product performance, field failures, and installers' demands for changes to boiler specification, dimension, size and component positioning within the boiler. Service engineers experiences from the field about appliance failures and customer complaints also serves as valuable input for product improvement.

Each production site within the case company has their own in-house service organisation and deals mainly with product brand manufactured for the market in their particular country of operation, except in smaller countries where service function is outsourced to external companies. For example, the UK service organisation only deals with products manufactured for the UK market. The main responsibility of the service function is to attend to warranty calls, repairs, and service and deal with maintenance problems. Product installations including problems with installation are attended to by external subcontractors who are widely spread across the country. They also work within the guidelines provided by the case company. This research only focused on the UK service organisation within the case company, other service organisation in other production sites was not consulted due to time constraint.

The service organisation conducts their own quality appraisal in-house and is done by the regional service managers and service quality team. The service quality team liaise with R&D and continuous product improvement (CPI) team to conduct problem solving activities such as examining replaced parts in order to identify root causes of product failures or problems in the field. Service also supports the sales unit rather than any individual market brand. Their means of communication include meetings, service engineer memos (SEM) and email systems. SEM is specifically a technical memo; it is used to inform service engineers about technicalities within a product.

4.2.3 UK service operation

The structure of the service operation in UK consists of the call centre, national service manager, divisional service manager, 14 regional service managers, over 180 service engineers and 40 external agents. The service operation is grouped into regional areas of UK: south, west and north. An equal number of service engineers are located in each region. The service engineers and agents both report to the regional service manager and divisional managers.

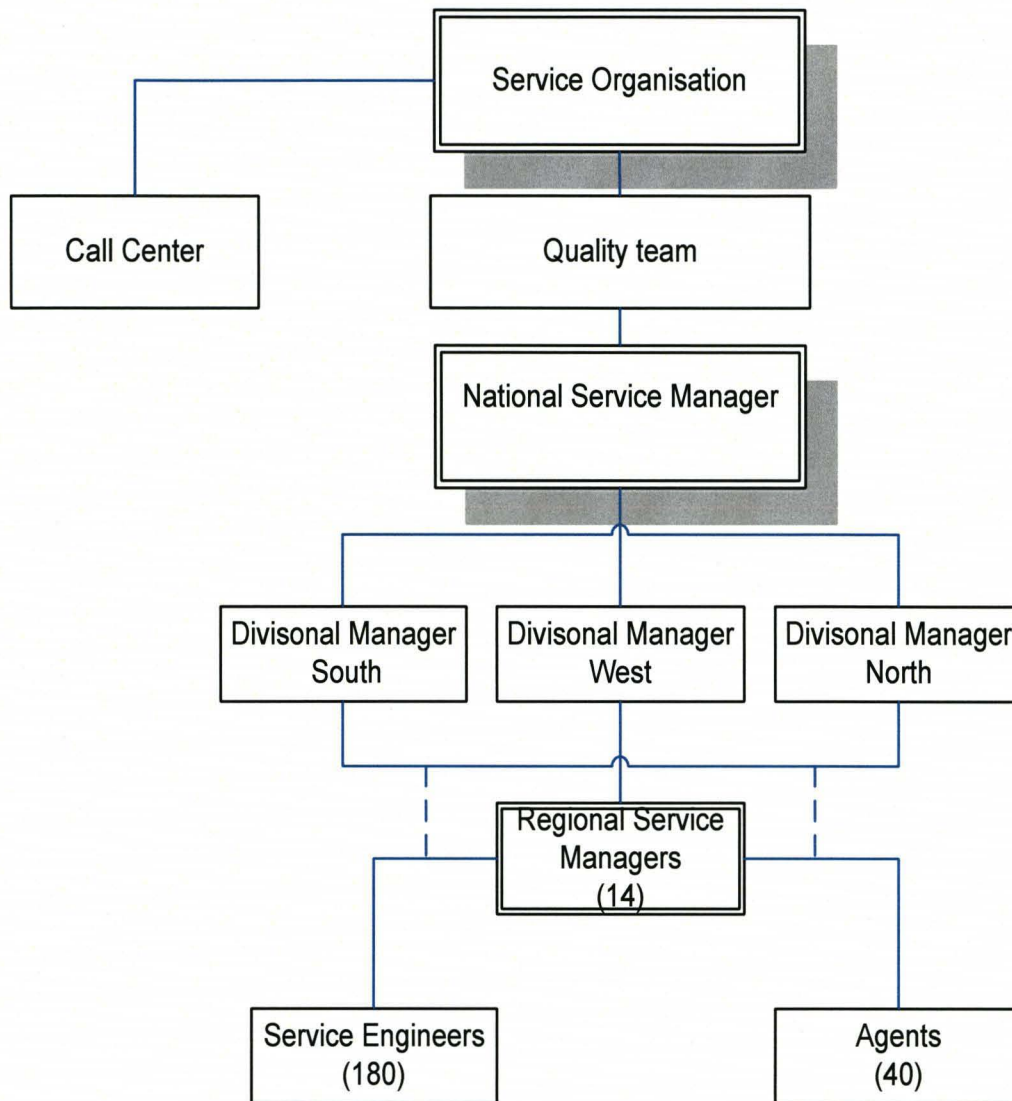


Figure 4-3: Service organisational structure

The call centre is the first point of contact for customers reporting a faulty appliance when making a complaint. Fault descriptions and product details are taken from the customer and recorded in the call centre system. This leads to the generation of a so called 'repair jobs', which is allocated to an available service engineer within the local vicinity of the customer's residence. Service Engineers work from home; therefore repair/servicing jobs that are allocated to them are within their local geographical region. Engineers pick up their repair job schedules for the following day at the end of each working day. At the start of each working day, the service engineer is required to ring the customer with the estimated time of arrival (ETA) at the customer's site. The task of the service engineer is to repair the failed product as reported by the customer. Once a call is assigned to an engineer, it is the responsibility of the engineer to resolve the field problem. If engineers have to order and install replacement parts, they would ensure that a repair job is rebooked.

4.2.4 Role of quality planning in case company

The case company quality organisation is organised to provide efficient operational support. Figure 4-4 illustrates the Group's quality structure.

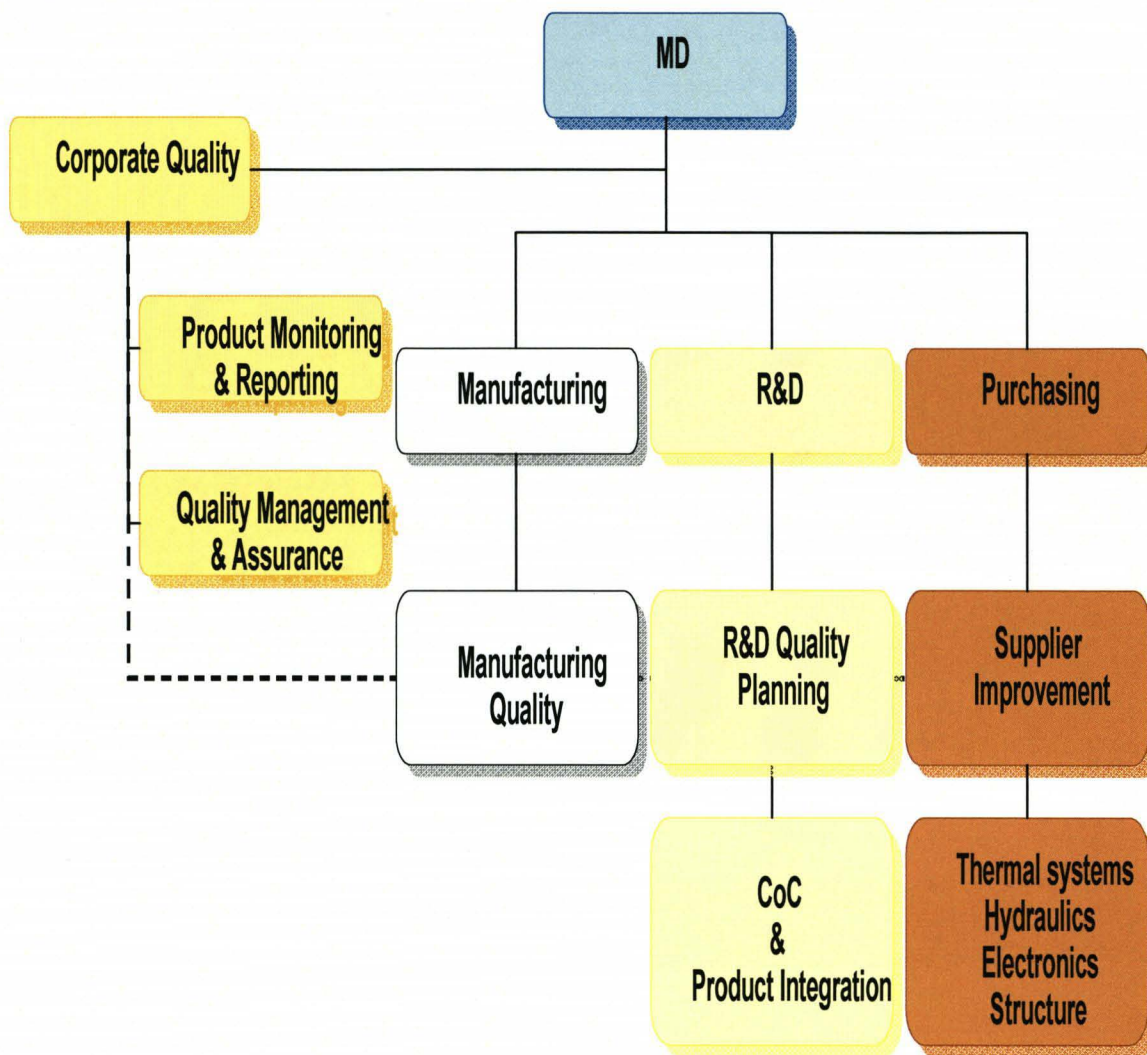


Figure 4-4: Vaillant Group Quality organisation

The quality of product development projects are monitored by the R&D quality planning team. The team is responsible for the prevention of failures by assuring product quality using approved processes and intelligent/effective testing procedures and, of course, assisting in the creation of robust design at the early stage of product development. To assure quality driven product life cycle individual quality targets are defined for all components in order to reach the company's "1-digit" failure rate ambition for products in the field. The main responsibilities of the R&D quality planning teams is to focus on the avoidance of problems this is achieved through activities such as coordination of failure prognosis, conduction of FMEA activities and the reviewing test plans such as functional, lifetime, field test. R&D quality planning team act as the link between service and design team and are involved in every stage of the product development process in preventing failures and assuring the quality of the products. The diagram in figure 4-5 illustrates quality planning activities as a link between the different phases of the company's product development process, starting from using market complaints data to create top of house (TopH) requirements when conducting quality function deployment through to field test.

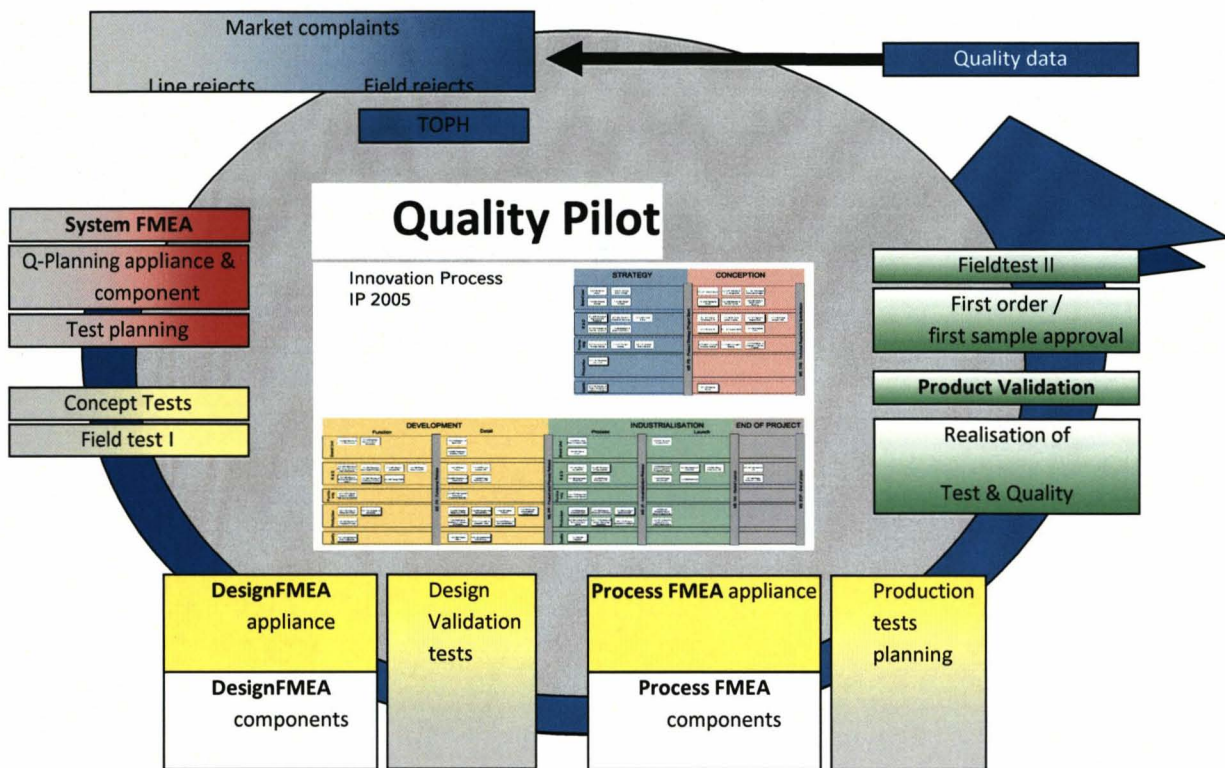


Figure 4-5: Conjoint quality planning over the entire Development Process (Vaillant Group presentation, 2005)

4.2.5 Role of design in case company

The company's design process is divided into two phases; development function and development detail. The former is concerned with validating key functions of the new product by subjecting prototypes to laboratory tests. In the latter phase of the design process, the product design and production plan become fixed. Necessary parties receive drawings and relevant documents on the product design. After the completion of the gateway review, funds are made available for production.

There are two types of roles of design engineers within the case company; the first is the construction design engineer who is responsible for integrating all the modules of the appliances. The second is involved in the design and development of parts for the appliances. Between these two roles, design engineers are responsible for the design and function of parts & products, the standardisations of parts and features, defining group-wide specification, packaging and documentation, integration of modules, drawings and development of prototypes and carrying out design change requests (Vaillant Group presentation slide, 2005).

4.3 Findings from Empirical study

The analysis of data collected and findings from the empirical investigation have been categorised into two major domains namely 'Feedback Process' and Field Data' as shown in Figure 4-6.

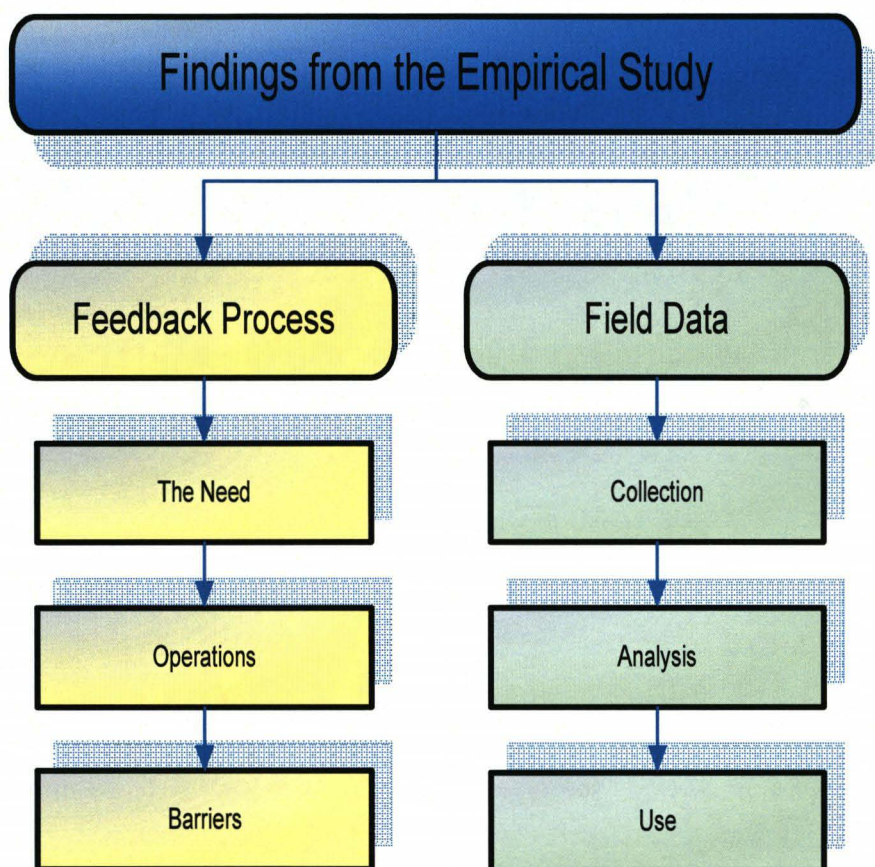


Figure 4-6: Discussion Map

The first domain concerns the management and organisation issues relating to the feedback process and the second is focused on processing and application issues relating to the field failure data.

As a reminder, the objectives of the empirical investigation were:

- to understand the current field failure feedback process from service-to-design;
- to identify limitations and potential improvements associated with feedback process;

4.4 Feedback process

The aim of this section is to present the findings on the feedback process from service-to-design. The key findings concerning the feedback process are shown below in figure 4-7.

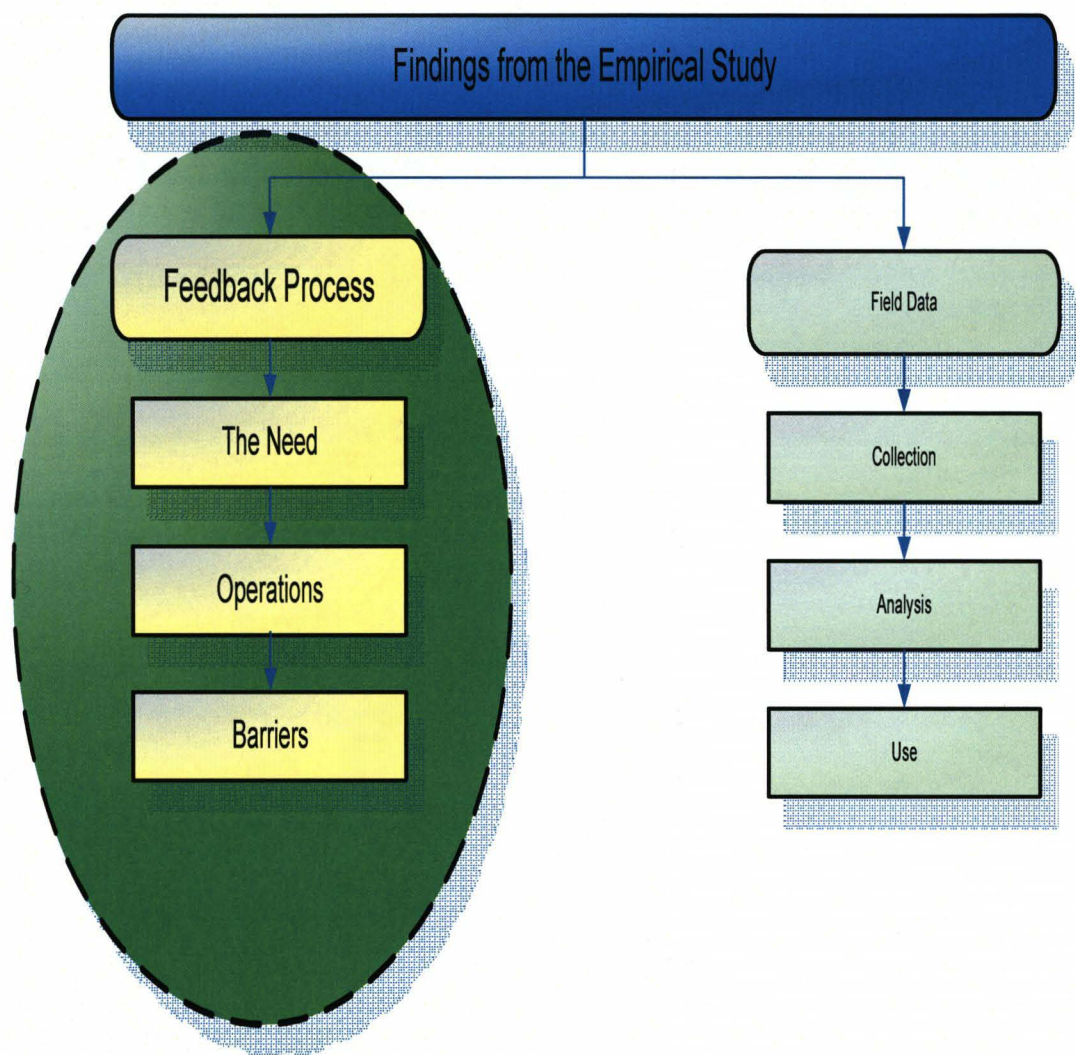


Figure 4-7: Key findings on feedback process

The charts in figure 4-8 to 4-9 presents the result of the questionnaire survey conducted with design and service engineers in the case company. Discussion in subsequent sections will make reference to these results to support the findings from the investigation.

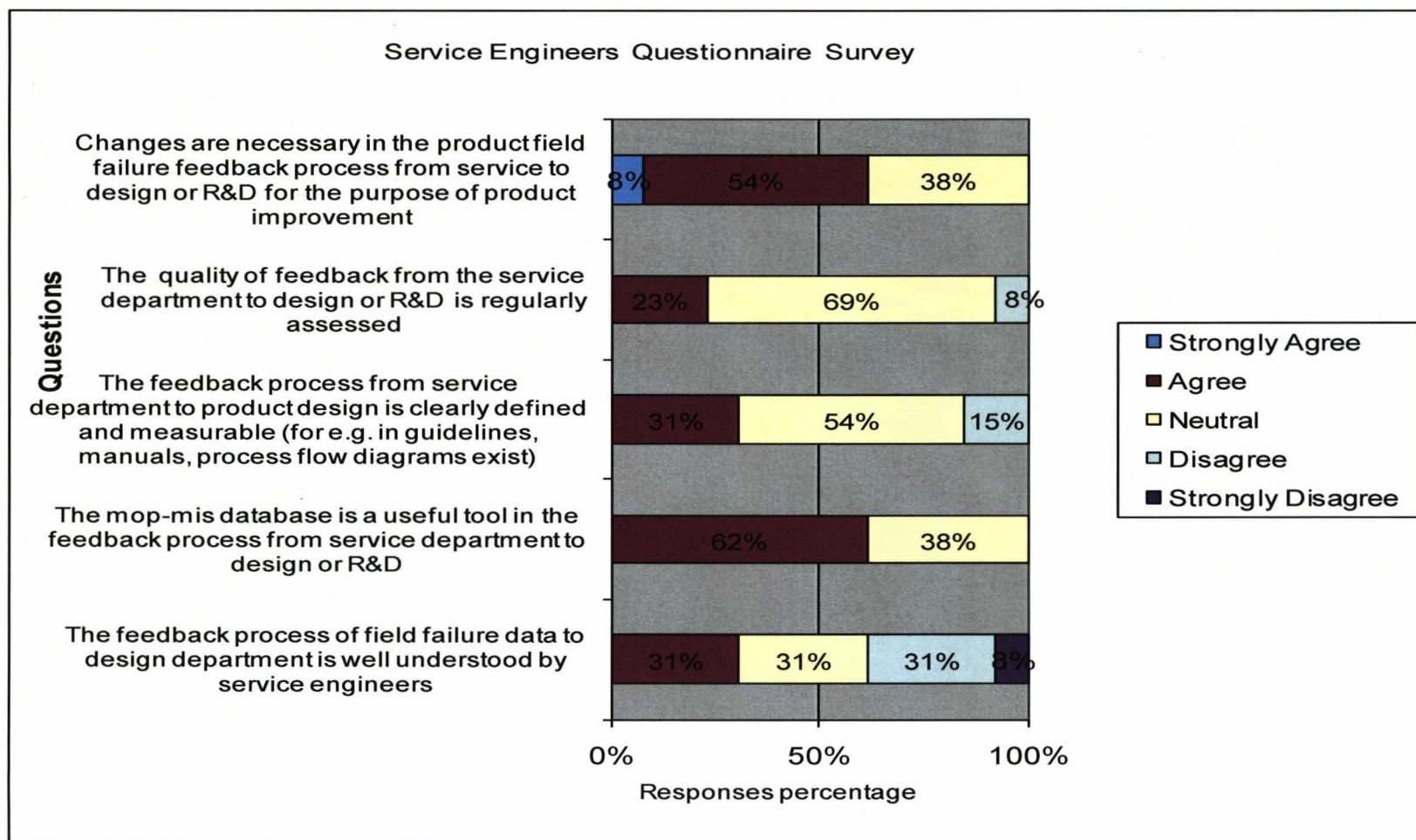


Figure 4-8: Service engineers' questionnaire survey response on field failure data feedback process

Design Engineers Questionnaire Survey

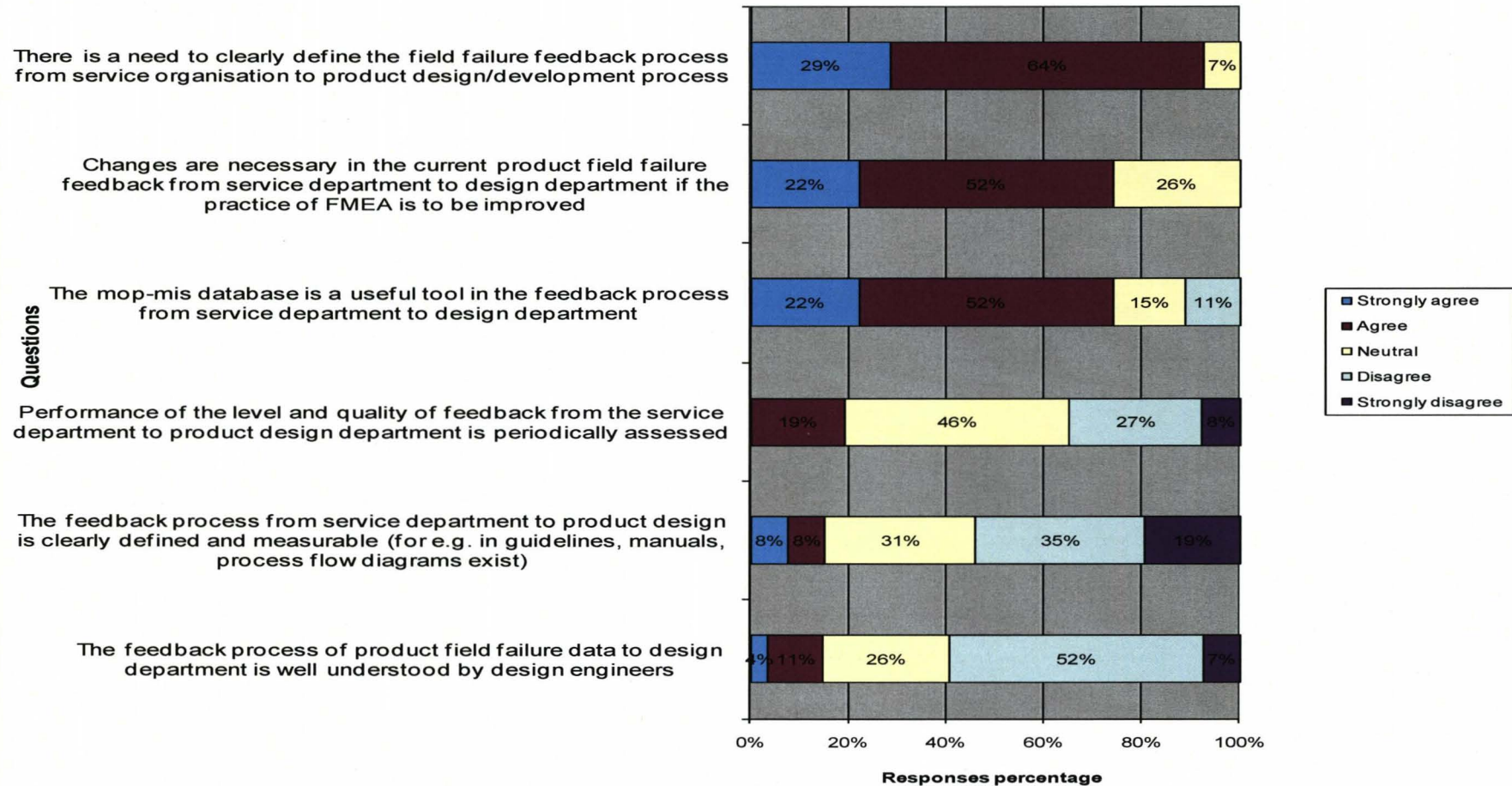


Figure 4-9: Design engineers questionnaire survey response on field failure data feedback process

Table 4-2: An overview of the Interview Survey

	No of interviewees	Examples of interviewee roles	Total no of interview hours	Total no of Interview transcripts pages	Questionnaire Response returns
<i>Design</i>	9	<ul style="list-style-type: none"> • Innovation engineer construction/Design-condensing boiler • Innovation engineer construction/Design-non condensing boiler • Innovation engineer construction/Design • Project leader Innovation Thermal • Team manager Test department • Innovation engineer development- Hydraulics • Innovation engineer construction/ Design-Hydraulics 	38	150 *Note* Some examples of the interview transcripts can be seen in the appendix II.	28
<i>Service</i>	4	<ul style="list-style-type: none"> • Field Service Engineer • Service Quality Manager 			13
<i>Quality</i>	5	<ul style="list-style-type: none"> • Project leader -Continuous Product Improvement • R& D Quality Planning 			
<i>Total</i>	18		38	150	41

Table 4-3: An example of interview coding analysis

			Interviewees Code											
			A	B	C	D	E	F	G	H	I	J	K	L
Codes	Emerging Quotes and sub-themes													
6 FFD benefits	Field failure data benefits to product design	Categories												
6.1 Failure Modes	Highlights possible failure modes	Process operation			☐		○					☐	☐	
6.2 Improved Design	Improve product design using outcome of failure analysis	Process operation	●	●	☐		●			☐	●			
6.3 Lesson Learnt	Use experience of previous failure of similar product	Knowledge reuse	☐				●							
6.4 Solution Implementation	Implement solutions of previous failures in new project	Knowledge reuse	●	●			●			○	☐			
6.5 Interrelationship	Link field failure data to occurrence in fmea	Process operation	●		○	○	○			○	○	●	●	●
6.6 CPI	Helps with continuous product improvement	Process operation			☐						●	●		
7. S-D Feedback attributes	Improving feedback from service-to-design		●	●	☐		●			☐	●			
7.1 Communication	Better communication between service and design	integration mechanism	●	○	○	☐	☐	○	○	○	○	●	●	
7.2 workshop	Organise more service/design workshop/meetings	integration mechanism	●	●	☐					○				
7.3 Information exchange Forum	Provide forums for exchanging information, evaluate field data and provide problem solution updates	integration mechanism	●	●	☐					☐				

Indications ● strong emphasis ☐ Slight emphasis ○ Low emphasis

The following discussions are drawn from the interview and questionnaire survey. *Note* - Coding structure is presented in an excel sheet.

Table 4-4: An overview of quotations from the emerged themes with their frequency of emphasis

Theme	Respondent Quotes	% of interview respondents
The need	<i>"There is a need to restructure the way the database presents the information".</i>	60%
	<i>"The important thing is to improve how the service engineer gets the failure data and not the database itself, not the structure. There is a need to improve how the actual data is captured".</i>	40%
	<i>"The information on the failures in the field is very important. We use the field data feedback to check the occurrence of a failure in the field. Field data is needed and used at the early stage of the product development process"</i>	100%
"As-Is" Operations	<i>"There are so many lines of data; Failure database is not easy to use. It is currently difficult to extract the information out of the failure database, data need interpretation and this requires experience. At the moment this is done by the quality team".</i>	10%
	<i>"I think the feedback process is quite well described on how we should handle it. I think we have to investigate more that we monitor it and we really do it".</i>	10%
	<i>"There is no formal document that tells you how to carry out the feedback process. The IP only has separate process description of the different activities involved in the feedback process".</i>	90%
	<i>"We often do not know why a service engineer has changed more than one parts when repairing a boiler"</i>	83%
Feedback process barriers	<i>"There is no link to the history of a failed part on the database"</i>	80%
	<i>"No direct feedback from technical support[service engineers]. There is a very long period before feedback is obtained, it takes us a long period to know about a failure in the market after launch"</i>	75%
	<i>"Level of details in the mop-mis database is not enough. The feedback is not exact enough. We need to have more detailed information about the actual root cause of the failure"</i>	77%
	<i>"There is nobody that takes really care about the failure analysis. Is it really strictly recommended that someone from Continuous Product Improvement team has to take part? Is there an audit. Is there any check. Who within the team is responsible for taking the failure data from the mop-mis to use in the product design improvement"?</i>	16%
Collection	<i>"The failure reporting system does not allow us [service engineers] to record information that represents what was done in the field. Some of the available options are not representative of the field problems. For example there is no option to record fault code unless you put it in the free text option. There is a need to breakdown some of the failure categories a bit more".</i>	22%
	<i>"The quality of data collected is poor. The level of details of data recorded in the mop-mis especially in the free text description is a problem. For example a service engineer can put damaged, and this could mean anything. It is difficult to extract relevant information out of it".</i>	78%
	<i>"It is difficult for design engineers to interpret failure data; we cannot look beyond the data. Data analysis requires the experience of the quality team (CPI); they provide the designers with the result of the analysis".</i>	78%
Use	<i>"The quality of the field data affects it use. To use it, you have to go deeper in the analysis if you really want to detect the actual failure causes".</i>	83%
	<i>"The feedback process is used differently across all three functions. Failure data helps us to improve both current series and new generation of product design.</i>	100%

4.4.1 The need for a feedback process

The case company aims to deploy a preventive quality management approach to enable the organisation to generate robust product designs. However, this is only possible through effective feedback of existing product failures from service into the product development process which allows them to focus on future problem avoidance. According to one of their quality managers;

"Preventive quality management enables us to be proactive [about identifying product failures]" (Vaillant Group quality in planning presentation, 2005).

Product field failures are an inevitable part of a product lifecycle and cannot always be avoided or envisaged upfront. Therefore feedback concerning product-in-use from the field is required to mitigate potential product failures and enhance overall product performance. Design, quality and service engineers highlighted that the need for service feedback is key at the early stages of product development for helping to specify customer's requirements by incorporating the so-called "voice of the customer".

"Feedback of field failure data is needed in design process as soon as possible. We need it at strategy phase when we make part per million level of the reference product. We need it for the modification from old boiler to the new boiler to make estimate for the new prognosis". (Quality Engineer, Respondent A, Transcript 1, p7).

"Field data is used in the very early stage. It is used for writing requirement for the new product" (Design Engineer, Respondent G, Transcript, 7, p6).

Product-in-use feedback from the field provides insight into aspects of the product design and manufacture that need modifications to prevent re-occurrence of failures in new generation of products.

The feedback process from service-to-design functions is an invaluable learning process. For example, designers use feedback data for learning from design failures and making design changes, quality engineers use it for quality assurance purposes, and the continuous product improvement team use it for generating solutions for new working practises. Ultimately learning from product failures in the field enables the case company to stay competitive.

The effectiveness of a feedback process depends on the levels of continuity, timeliness, detail, accuracy, and relevancy of the data that is being transmitted. An emerging concern relating to feedback is the level of detail about product failures that are communicated back to the designers by service engineers, as articulated by one design engineers as follows;

"Service engineers' change parts but do not check if the part is really defective. One of the main problems we have is identifying how many parts they have changed and the reasons for changing them" (Design Engineer, Respondent H, Transcript 8, p3).

"What hinders the feedback process is the quality of data taken from the field and in many cases you get feedback very late" (Design Engineer, Respondent G, Transcript 7, p5).

These responses confirm there is a need to provide explicit and accurate descriptions of actions taken by service engineers to resolve a field problem. 64% of design engineers agree that there is a need to clearly define the field failure feedback process from service to product design/development. Important issues are concerned not just with recording failure information as routine activity suggest, but should also include detailed accounts of the failure modes and corrective actions taken to repair the faulty appliances, and the reasons for installing replacement components. It is important for service engineers to acknowledge that they need to be more explicit and their feedback should entail a useful record of events to product developers for effective problem analysis and resolution. According to one interviewee,

"The feedback data is always available however; the problem is it takes a lot of time to make the right analysis" (Quality Engineer, Respondent A, Transcript 1, p8).

The interviewee comments refer to the time consuming nature of analysis and problem resolution, resulting from inaccuracies and insufficient details in the data recorded.

4.4.2 Current operation in feedback process from service-to-design

The feedback process is triggered when customers make a complaint to the service centre about a product malfunction. It is the responsibility of the centre to ensure that customers are satisfied with their product and therefore assign field service engineers to resolve client problems. The recorded failure information by service engineers is a major source of feedback to the R&D organisation, to ensure designers are aware of how well their products are performing in the field, as described by one of the design engineers;

"For me it is very important to get failure feedback as soon as possible and as detailed as possible. Especially if you have new product [launched] you need this information to track the quality in the field" (Design Engineer, Respondent G, Transcript 8, p8)

Once the failure data is recorded using a hand held personal digital assistant (PDA) into the failure database called MOP-MIS by service engineers, the data is available yet not easily accessible for use by designers and other functions such as production and quality in their functional roles within the product development cycle. Further problem solving investigations on the data are conducted and the result of the analysis and their interpretation can be usefully integrated into new product design activities. Figure 4-10, illustrates a high-level view of the current feedback process from service into the product development process.

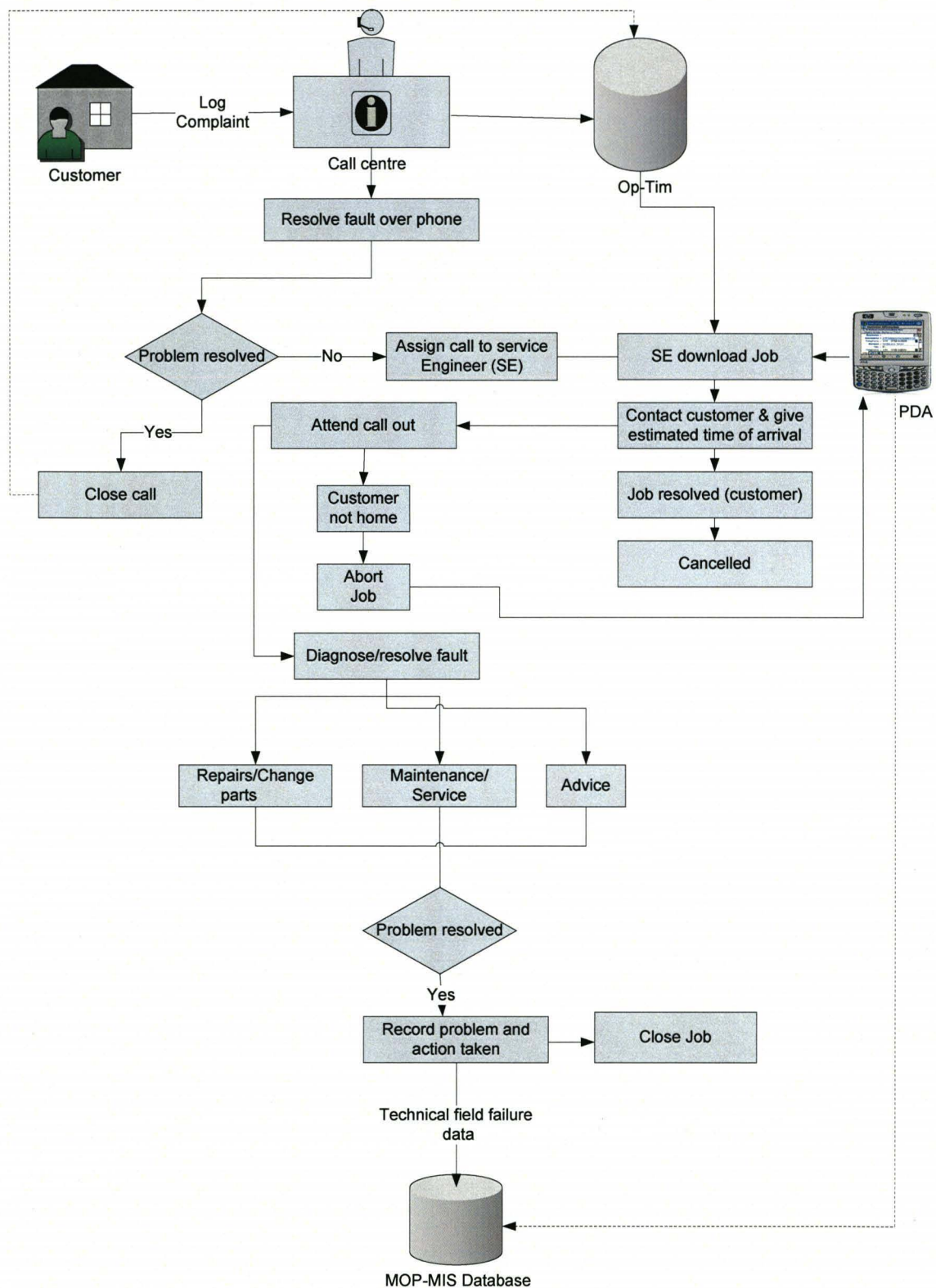


Figure 4-10: Current field failure feedback process

Every product development project within the organisation is assigned a quality planner, who is responsible for analysing the raw field failure data from service

and a continuous product improvement engineer, who is responsible for finding solutions to the problems identified in the field. The analysis reports are subsequently disseminated to the product development team for use in making product improvements. The continuous product improvement team (CPI) communicates the levels of failures to the designers. As mentioned by one of the design engineers;

"Mainly the quality planners will give [field] feedback on the existing product. They highlight problems with the existing series and [forecast] expected failure [rate] if no changes are [carried out]. CPI actions on existing boilers are used in the new boiler. If the CPI team are working on a problem to improve [product failures], they notify designers. For example, there was a problem with gas pipe, it was too small for big appliances, the CPI notified us that they are working on a bigger gas pipe, and this information should be considered in [the development of] new boilers" (Design Engineer, Respondent G, Transcript 7, p3).

Feedback of the performance of products in the field is an essential element of the continuous product improvement process. Without it, design engineers would not realise the unintended consequences of their design decisions; and so little action would be taken to improve future outcomes. Sufficient feedback provided to design engineers informs them of not only the general levels of customer satisfaction, but also the efforts needed to provide improved products and hence better satisfy future customer requirements. Solutions implemented by designers are occasionally fed back to service engineers. Therefore, if they encounter similar problems in the future, they are able to diagnose the problem quickly and take corrective actions as appropriate. In light of the obvious benefits of a feedback process, the findings show that 74% of the design engineers and 62% of service engineers strongly agree/agree that changes are necessary in the current product field failure feedback from service-to-design for the purpose of product improvement whilst 38% of service engineers and 26% of designers have a neutral view on this issue.

One such change is in the failure (MOP-MIS) database used for recording product failure data from the field by service engineer. However, the perception of the usefulness of the failure database varies between the design and service engineers. Despite its usefulness the interview findings suggested that service engineers disagree that it captures all the necessary information about product failure for future corrective action. The reason for this limitation is partially due to the classification system of failure options given in the failure database which is inadequate for characterising product failures in the field. A design engineer mentions that;

"Field failure data is fed back into the design process through the reliability-prognosis where possible failures are identified and then through FMEA where potential failure modes are identified as well as failures that have already occurred in the field" (Design Engineer, Respondent F, Transcript 6, p5).

Having limited time and resources to attend to the data inaccuracies sometimes make it very difficult for the development team to seek additional field data and this subsequently forces blind investigations into a number of identified failure modes in the field. Further investigation priorities, after safety, are given to failures which have the most impact on the overall functional performance of the appliance.

The importance of the field failure data is not fully understood and appreciated as a valuable input for product improvement within the case company. It is evident that there is a demand for resources to ensure problems in the field are managed efficiently. A new project appears to take first priority when resources are allocated; and the remaining resources are allocated to the investigation of field problems that need immediate attention.

It also appears that the costs associated with failure investigations and the necessary changes to resolve future problems also determine how product field failures are prioritised. Inevitably higher priorities are given to failures that are more cost effective to the organisation.

No formalised procedure of feedback process: There was very little evidence of any formalisation of the product field failure feedback process and the activities it entails. 54% of design engineers strongly disagree/disagree, 16% strongly agree/agree and 31% takes a neutral stance that existing feedback process is clearly defined and measurable whilst 54% of service engineers indicated a neutral stance, 31% agree and 15% disagree. Procedures for collecting, processing and using the feedback and related data from service required in the context of new product improvement were largely informal. There was no explicit documentation that illustrates how the feedback process operates. However, the large percentage of neutral stance expressed by the service engineers could be because the existing process is conducted using the tacit knowledge and experiences of the personnel involved. Based on the findings from the interview with service engineers, they believe there are procedures in place for executing service duties but do not have the full understanding of how the procedure or outcomes from the procedure fits into other functions. A lack of formal process management also adversely affects the way resources are allocated to generate and process service-to-design feedback information. As stated by one of the quality engineers;

"sometimes the capacity is missing to conduct a better evaluation of problems on existing boilers in order to reduce the failure or to improve them in the new product"
(Quality Engineer, Respondent A, Transcript 1, p6).

Also, there is no recognised method to assess the quality of the feedback information and to what degree the information was deemed successful in deployment. It is evident from these statistics that making the feedback process explicit will ensure that it is standardised, and thereby making it more accessible to more stakeholders and ensuring common understanding.

The feedback process appeared to be managed in an ad-hoc manner. It was not generally thought of as an integral or extended part of product development even though people understood the need for it. Responses from the questionnaire survey show that 39% of service engineers strongly disagree/ disagree, 31%

agree, 3% are neutral that the feedback process is well understood by them and 59% of design engineers disagree, 15% strongly agree/agree and 26% are neutral, that they fully understand the feedback.

4.4.3 Barriers to effective feedback

A major barrier to the existing feedback process is the lack of communication among the cross functional product development team members. This has led to the duplication of effort, especially in matching solutions to problems identified in the field. For example, similar problems that have occurred in other brand markets of the company are not effectively communicated between different product development teams and product brands market.

Whilst the continuous product improvement team discuss field problems regularly and possible solutions to them, their experiences tend not to be shared with the development team. There are problems in the field which cannot be discussed openly due to, for example, constraints imposed by confidentiality agreements between service and the development team. In such situations product managers are aware and they often communicate informally and on an adhoc basis with designers without disclosing full details of the problem.

Lack of direct communication between service and design engineers: A lack of direct communication between service and design engineers affects the timeliness of the feedback, which often means designers are not being made aware immediately of the product failure rates in the field. For example, it takes about six to nine months between the launch of a product and getting feedback on product failures. Speedy feedback is only obtained when there is a telephone hotline which directly links service engineers to designers. This is illustrated in the comments of the service and design engineers as follows:

"It takes a long time for us to know about a failure in the market after launch. In some project the design engineers has a hotline especially in the development of a new product. [This enables the designer to get a quick and direct feedback from the field on newly launched product]." (Design Engineer, Respondent D, Transcript 4, p3).

"Not all failures are recorded in failure database. For example if only one failure occurs in a newly launched appliance, R&D gets to know about the failure via a customer hotline". (Service manager, Respondent M, Transcript 13, P4)

It is not in the normal protocol of the service engineers' role to contact designers directly except in special circumstances when a highly complex and innovative product has been launched and is experiencing field problems. This would happen through a hotline setup for direct communication between service and design. In such situations this direct platform for communication is beneficial for both parties. It enables designers to have an immediate awareness of how products are performing in the field as well as support for the service engineer in resolving problems experienced. Nevertheless, even with a special hotline set up for direct communication; service engineers often do not know the designers and it would be impossible for them to contact the designers for technical advice on faulty appliances. According to the statement by one of the service engineers;

"I don't know who the designers are, I don't know who to speak to or send further information to, it is not in the etiquette of my role to contact them directly" (Service Engineer, Respondent M, Transcript 13, p15).

Another communication issue between service and design engineers is highlighted to result from their independent work. Therefore, there is a lack of understanding of the functional interdependencies within the feedback process. Insufficient communication between services and the product development team can also lead to a failure repeatedly re-occurring in products in different parts of the organisation's international business scene. It was also highlighted from the interviews that not all field problems are recorded in the failure database; some problems in the field are only discovered through informal communication with service engineers to detect errors. A disadvantage of insufficient and irregular communication between both units is, for example, if service engineers have ideas about how to resolve a known problem, or improving how things are done, there is opportunity for them to further brainstorm and share their ideas and generate possible solutions together.

The issue of communication between service and design is further exacerbated by the differences in language and culture. This makes it difficult for functional groups across the various R&D sites of the organisation to share their know-how and experiences about problems in the field and potential solutions. The products manufactured by the organisation have standard components across all product brands. It was observed from the interviews that if a problem and solution was identified for a particular brand in the UK market, it often not easily available to other product brands and market. Because the CPI team in both markets do not share their knowledge of problems identified in the field as well as solutions developed to address those problems, they often re-invent their own solutions. This hinders the opportunity for the organisation to enhance their learning efforts. Such knowledge exchange would prevent wasting time, money, resources and effort in finding solutions that already exist. Clearly, service engineers, designers, quality and other key functional teams involved in the product development process need to be communicating with each other on a regular basis to ensure valuable knowledge sharing.

According to one design engineer:

"The way designers do not talk about problems is a major hindrance to the feedback process. For example, in the CPI team, they discuss problems regularly and find solution to it. But they don't bring their experience into the development teams" (Design Engineer, Respondent B, Transcript 2, p4).

Lack of process management: One of the problems with the management of the feedback process is knowing how to gather feedback and then manage it effectively for use by the stakeholders. However, just having feedback isn't enough. As with any information, how you put it to use is just as, if not more,

important than possessing it. When asked if the performance and quality levels of feedback from service-to-design are periodically assessed, there was significant ambiguity in service and design engineers' responses. This shows that the assessment of the quality of the feedback process is not a priority. If there is no periodic assessment of the level of quality of the feedback process it would be difficult to assure the process is always efficient and optimised and identify areas for improvement. The diagram in figure 4-11 illustrates how the feedback process is organised. The input to the feedback process is conducted by the service engineers and this involves the capturing of the field failure data, the processing or transformation of these inputs is conducted by quality engineers, whilst the output is used in the product development process for either incremental or radical product improvement. However, within this case study company product improvements often amount to incremental changes.

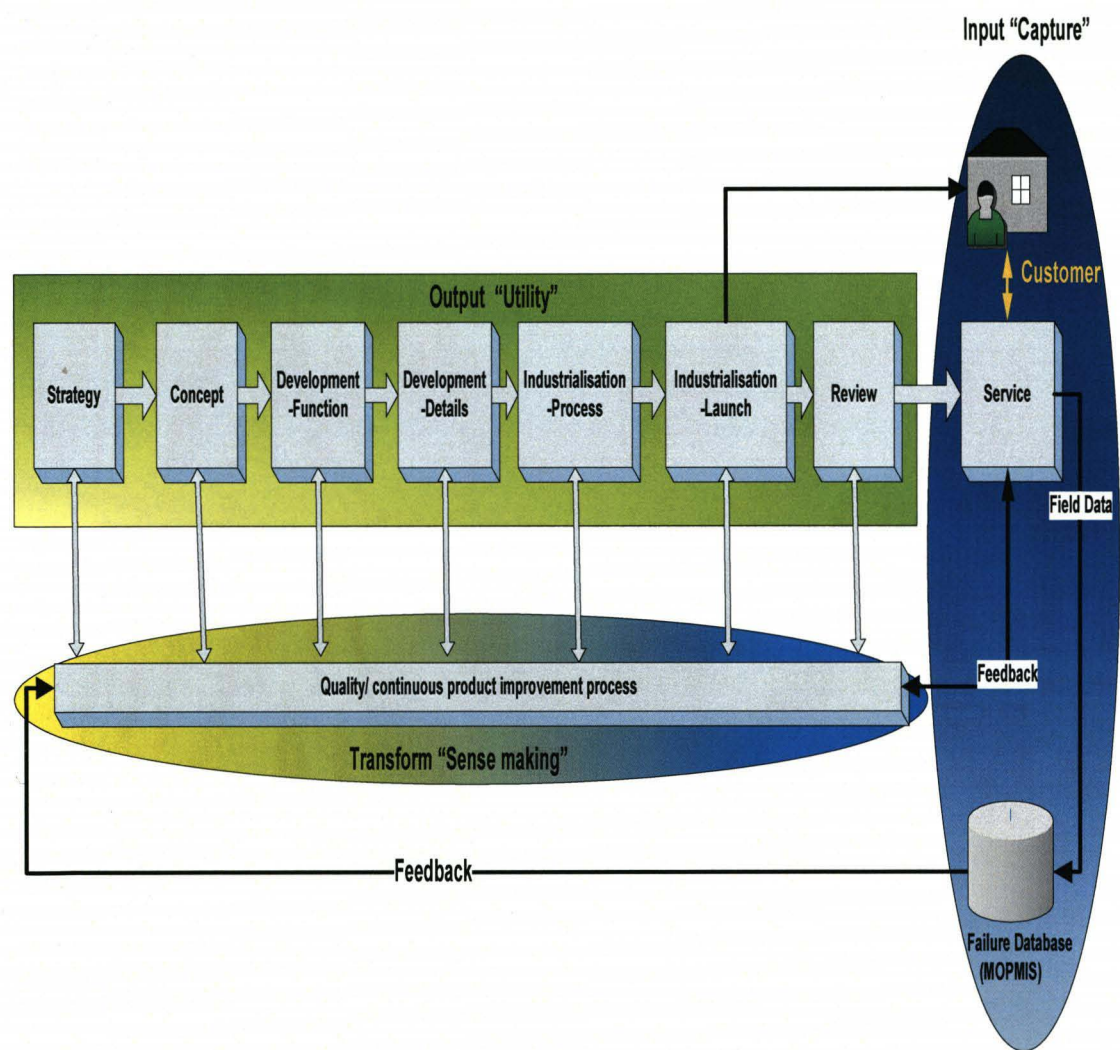


Figure 4-11: input/output feedback process illustration diagram

According to a service engineer;

"The failure recording system doesn't present service engineers with selective options that answer the engineers' questions. If the engineer has changed parts in the appliance, if he can't find it in the options presented by the system, then the engineer ends up selecting the option "others" which requires free text entry and it is difficult to extract information out of "others" (Service Engineer, Respondent L, Transcript 12, p6)

The feedback process lacks a process workflow that illustrates how the failure data is linked to the tools such as FMEA for the purpose of product improvement. According to one of the quality engineers:

"Is it really strictly recommended that someone from CPI has to take part [in monitoring the quality of the field data]? Is there an audit? Is there any check" (Quality Engineer, Respondent F, Transcript 6, p3).

It is evident from this quotation that there is lack of understanding of how the feedback process is managed. The management of the feedback process should be clearly understood by all the users of the process by defining the ownership of activities in the process, including quality checks and performance measures.

Another issue that demonstrates the lack of process management is that service engineers have problems describing faults within the data capturing system (so called MOP- MIS Failure database), whilst the quality and design team have problems with extracting relevant information from the description provided by them. According to a service engineer:

"Some necessary questions for recording accurate and detailed field failure data are not presented in the system. R&D need to know what information we are trying to put into the system, once they know that, they can ask us if the system ask the right questions for different types of fault. At the moment we are recording that there is a fault, not recording what is causing the fault". (Service Engineer, Respondent L, Transcript 12, p6)".

Lack of formal roles and responsibility: there is no appointed person or team who is formally responsible for ensuring the successful execution of the feedback of failure data from service-to-design. Although the continuous product improvement team and the quality planners are responsible for the analysis of the raw failure data and the interpretation of the data into a useful format for FMEA, there is no clarity as to who within this team is responsible for extracting the failure data from the failure database to use, for example, in FMEA. The current process does not establish the formal roles and responsibilities of the various stakeholders in the feedback process. For example, who should be responsible for measuring the performance of the process and performing an audit check on the quality of its contents? As mentioned by a quality engineer:

"Who within the team is responsible for taking the failure data from the failure database to use" (Quality Engineer, Respondent F, Transcript 6, p3).

According to a service engineer:

"The system needs a joint team effort between service and R&D. They need to come up with lists that suggests what is needed by service and what information R&D is looking for from the field". (Service Engineer, Respondent L, Transcript 12, p6).

Lack of efficient feedback facilitation tools and methods: there are two main feedback facilitating methods; the first is the product field failure database (Failure database), where all the raw data on field failures are stored. The failure database is easily accessible via the company intranet but the difficulty lies in using the data. 74% of design engineers and 62% of service engineers agree whilst 38% of service engineers are neutral and 15% of designers are neutral, 11% disagree that the failure database is a useful tool in the feedback process. However, despite the difficulties faced by design engineers in using the failure database to extract relevant information, poor data quality further affects its general usefulness. Potentially a well maintained failure database provides a vital link between service and product development through which problems in the field can be communicated. Forgiving its current hindrances the failure database is accessible to the feedback process stakeholders via the intranet but, they rely heavily on their previous experience to manipulate the data and extract real meaning. As stated by one of the service engineers;

"There is nothing proactive about failure database; there should be rules within the system which send an alert message to an appointed person in certain situations. For example, if more than 10 components of the same component are used within a week, then the system should send an email to the person in charge of such issue, to inform the person on the high usage on that particular component, for unknown reason" (Service Engineer, Respondent L, Transcript 12, p4).

Another comment states:

"People think Failure database will tell them everything about a failure. It will if the problem is only with one component but this is a multiple component appliance connected to other system. Sometimes it is one part affecting another part that causes failure and it is difficult to put this into Failure database, because it seems to be capable of capturing only single component failure. (Service Engineer, Respondent L, Transcript 12, p6)".

The current field failure capture system (MOP-MIS failure database) lacks the capability to capture the root causes of a failure. Often the effects of a failure are recorded.

" I think the Failure database gives us a clear picture on the figure effects but if you really want to know the failure causes you have to investigate further" (Quality Engineer, Respondent F, Transcript 6,p5)

The second feedback facilitating method is FMEA, which is a quality assurance technique for evaluating the potential failure modes. From time to time product failures have been identified in the field; the feedback from these failures is used in FMEA and has led to the need for further investigations in order to find effective solutions to the failures. The application of FMEA encourages sharing of information, experience and knowledge among the cross functional teams involved in the FMEA process. Their knowledge and experiences of the products and current problems in the field are required for identification of failure modes, calculating the risk priority number and assigning actions to detect failures or eliminate failure before it occurs. The outcome of the FMEA process is implemented in the design process. Despite the benefits offered by FMEA, the FMEA processes need to be improved to have a better impact on design. This is emphasised in the following comments from some of the design and quality engineers:

"There is no common FMEA database of potential failure data; it is not possible to look into different FMEA to look if different teams had the same or similar problem and how it was solved. Whenever we detect some possible failure, there is always a new attempt to solve them" (Design Engineer, Respondent B, Transcript 2, P2).

"Until now every project creates its own system FMEA. Having a standardised database in future means that every project can take out of this database [without having to start from scratch]" (Quality Engineer, Respondent A, Transcript 1, p4).

"There is a need to have an historic database of previous failures and solutions and I think it is very important to visualise it, not only to have textual description. A picture normally tells a lot more than a text" (Design Engineer, Respondent C, Transcript 3, p2)

"We have to think about developing a database, which has the capability to share older experiences of problems that have occurred in the past product. In this database all the historic FMEA should be stored. It would be a kind of template that can be used in developing improved product in the future". (Quality Engineer, Respondent F, Transcript 6, p1)

It is evidence from the above statement that lack of efficient facilitating tools and methods sometimes creates duplication of effort and re-inventing the wheel.

4.5 Feedback process summary

The findings strongly emphasise the need to change the current feedback process to ensure it is conducive to improving product development through the product quality and service process. There appear to be so many neutral responses to the questionnaire, this might be because respondent were trying to be cautious on the responses so as not too appear either to positive or negative but rather choose to sit on the fence. This might have influenced the results by making it inconclusive. To avoid this problem further understanding and clarification on specific issues

with high percentage of neutral stance were obtained from the interview survey to establish more specific information to the responses given. Service plays a vital role in the successful operation of the feedback process and the field information captured serves as inputs to failure analysis and other activities towards product quality improvement. The findings suggests that it is important to have a recognised feed-back plus a forward-feed of information among the cross-functional teams involved in the design, development, servicing and continuous improvement of the different product brands. One quality engineer stated that:

"One of the prime challenges of optimising the feedback process is to develop a formal, more structured and easy to use feedback method" (Quality Engineer, Respondent J, Transcript 10, p3).

The following comments characterise different ways to improve existing feedback process as suggested by the interviewees from the service, quality and service functions:

- *"Better communication and interaction between design and service organisation".*
- *"Integration of field data into FMEA for better failure analysis and quality improvement".*
- *"Standardise failure modes".*
- *"Develop a standardised methodology of feedback process".*
- *"Organise regular service/design meetings/workshops".*
- *"Create a forum for exchanging field failure information".*
- *"Provide detailed information about product in use failure modes".*
- *"Provide early feedback via telephone hotlines"*
- *"Involve service engineers in functional design".*

The feedback process can also be optimised by better managing the closing of communication loops between service and design engineers. According to a design engineers:

"I think the very important thing is that there are some close loops in the organisation but at the moment they are based on personal contact. I think that is a challenge to make it more structured or an easier way to have this feedback process. But I think it is very positive that there is a structure". (Design Engineer, Respondent G, Transcript 7, p5).

Furthermore, using approaches such as round table discussions focussed on field failures augment understanding that is not captured in the failure database. According to one of the design engineers:

"In the past, an action list approach was used to capture service engineers concerns on challenges faced in the field. The action list is an excel sheet used by service engineers to report their concerns based on their experiences with the customer, the challenges faced, their fears, their anger. Generally the action list is a medium for voicing their opinion on a product. The list is passed on to the CPI team to investigate each concern or comment on it. Examples of such CPI comments are;

- 'we are aware of this problem',*
- 'we'll have a solution in two months time',*
- 'we are not working on this problem at the moment due to several reasons, if someone thinks it is important we'll have to set a priority',*
- 'This problem is work in progress" (Design Engineer, Respondent C, Transcript 3, p5).*

Concerns articulated in the action list provide information about the challenges faced by the service engineers in the field. According to the respondent, the action list is no longer used within the organisation because there are not enough resources to carry out further investigation on the issues raised.

The availability of a telephone hotline which enables direct communication between design engineers and service engineers also optimises the feedback process. According to a design engineers:

"If you wait until you evaluate the failure database you have three to four or five months before you get feedback information. If you have a direct contact with the service engineer, within the first two weeks after the market introduction and you have five calls with the same problem, you don't have to wait for the failure database to increase before you start investigating the problem and find a solution to it" (Design Engineer, Respondent C, Transcript 3, p5).

It is evident that the hotline is a powerful mechanism to provide speedy feedback on product failures in the field and prevents typically long delays of five to six months in obtaining feedback via the failure database.

4.6 Findings: Field failure data

This section presents the analysis and results about field failure data from the empirical study. They are clustered into the following three main points of discussion:

- Field data collection
- Field data analysis
- Field data use

The diagram in figure 4-12 highlights the key discussion points from the findings on field failure data.

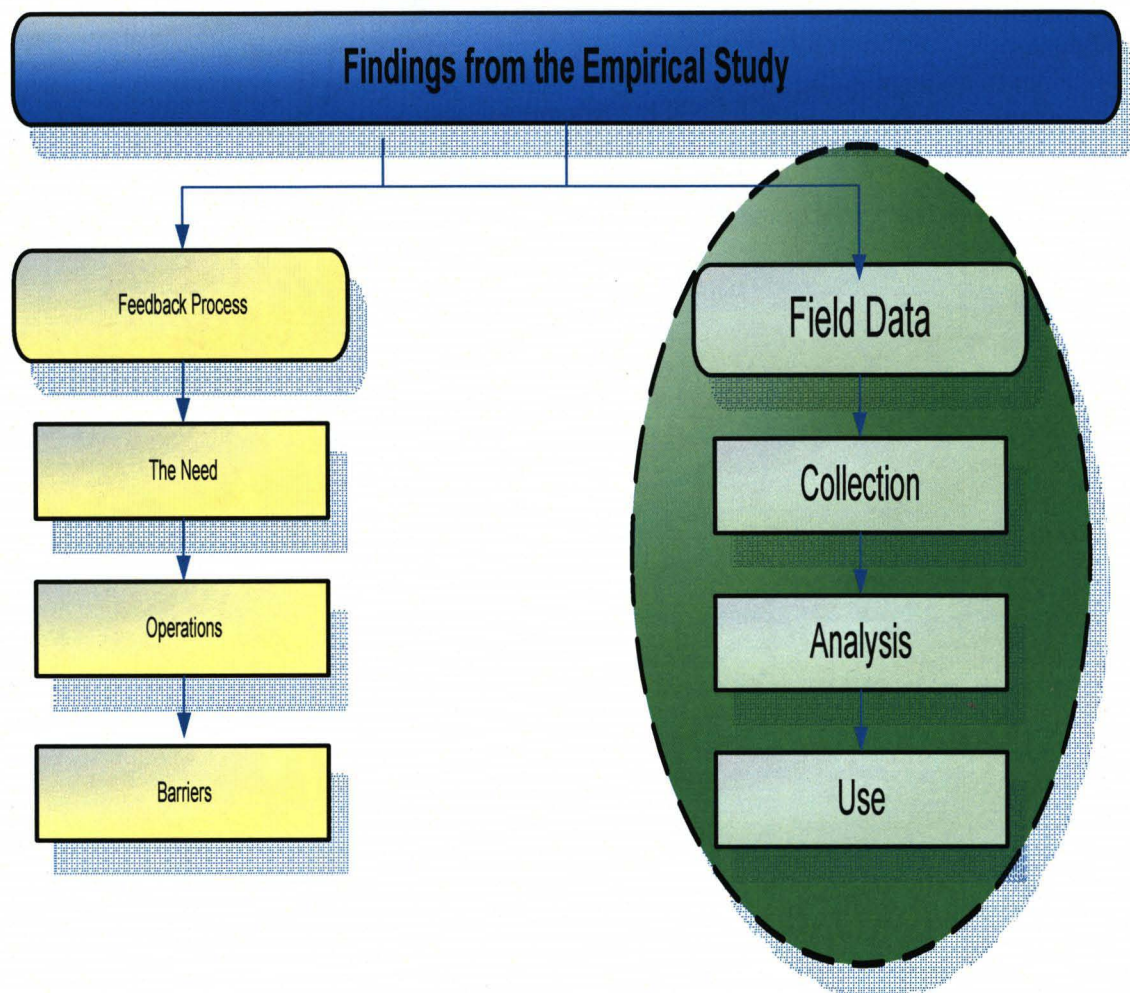
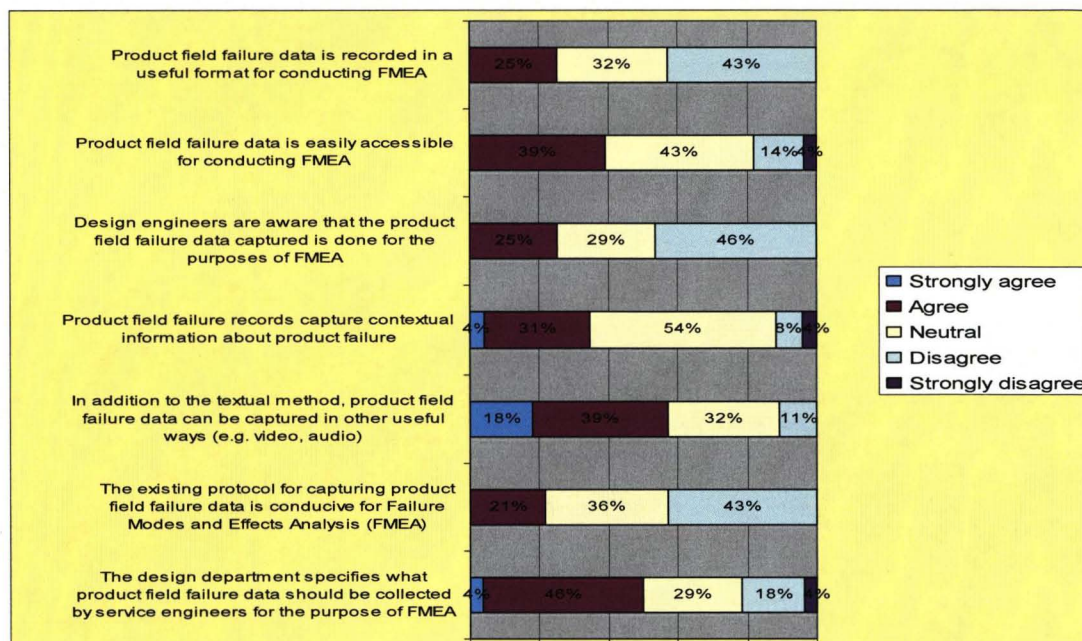


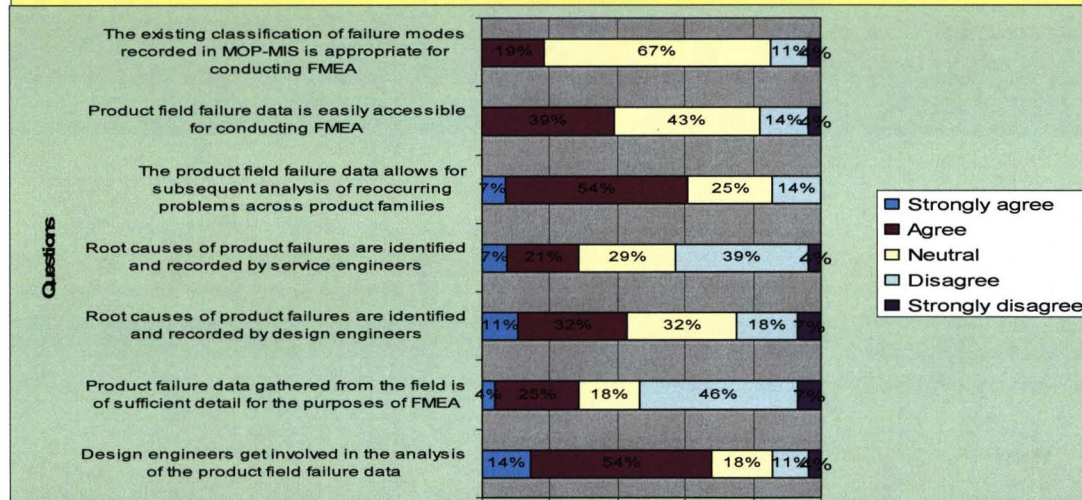
Figure 4-12: Field data discuss map

The charts in figure 4-13 and 4-14 present the result of the questionnaire survey conducted with both design and service engineers within the case company.

Collection



Analysis



Use

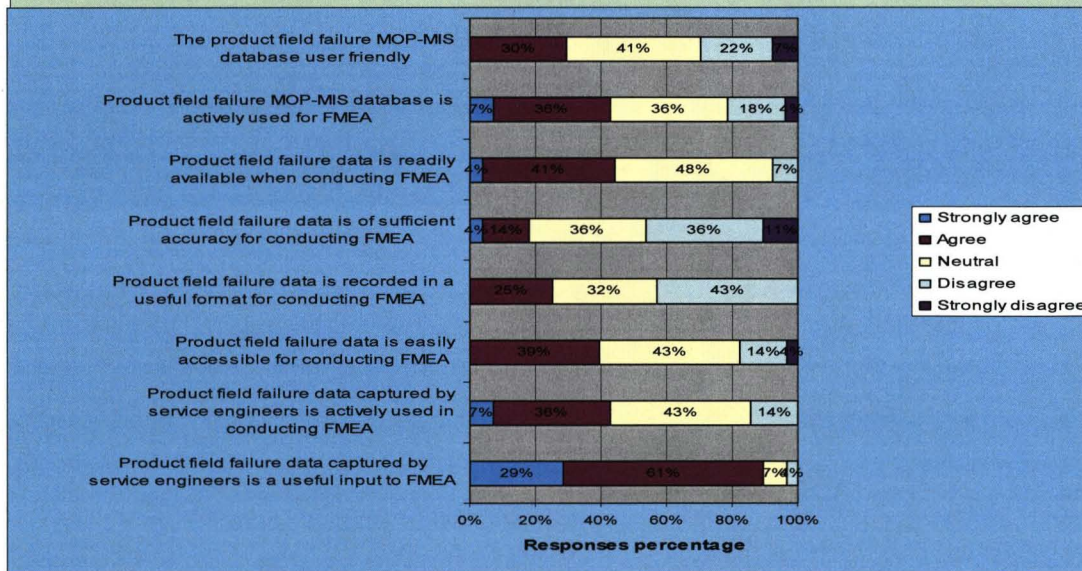


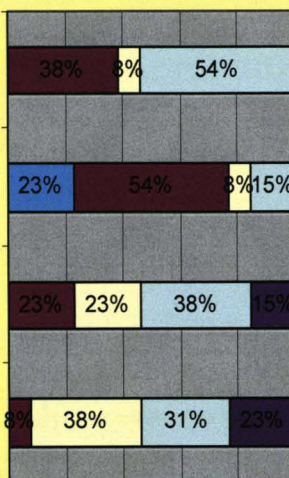
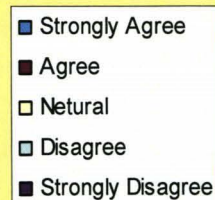
Figure 4-13: Design Engineers Field Failure Data Response Survey

Collection

Failure data recorded at end of each service callout give a true reflection of the problems in the field.

Service engineers are aware that the product field failure data is captured for the purposes of future product improvement.

The product field failure data reporting worksheet (mop-mis) captures all the necessary information about product failure. In addition to the textual method, product field failure data is captured in other useful ways (e.g. video, audio, pictures).



Analysis

Questions

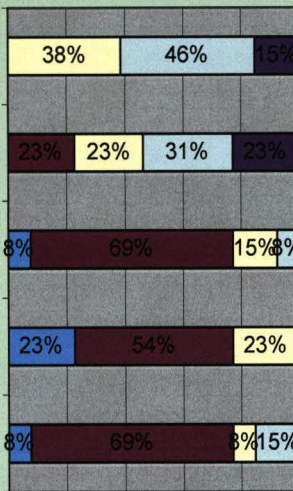
Classification of failure options given in the field worksheet (mop-mis) is adequate for

Service engineers are involved in analysing field failure data

The product field failure data allows for subsequent analysis of reoccurring problems across

There is a need to improve the way failures are classified, so they better represent the actual

Root causes of product failures are identified and recorded on the field worksheet (mop-mis)



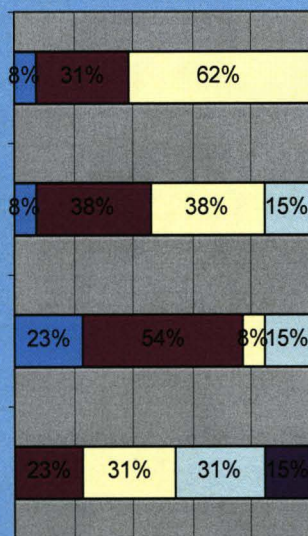
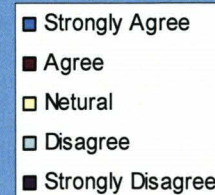
Use

The product field failure data is a useful input to System level Failure Mode and Effect Analysis

Design engineers use the field failure data captured by service engineers for the purpose of product improvement

Service engineers are aware that the product field failure data is captured for the purposes of future product improvement

I have a good level of understanding on Failure Mode and Effect Analysis (FMEA) and its application in product development



0% 20% 40% 60% 80% 100%

Responses percentage %

Figure 4-14: Service Engineers Response Survey

4.7 Field failure data collection

Field failure data are records concerning product-in-use failures. Subsequent analysis of these records provides statistical information on how well a product is performing for the customer. In the case company field failure data is collected to monitor product performance in the field, and the outcome of the analysis is used for improving future generations of products. Figure 4-15 illustrates the research findings that concern field failure data collection to be discussed in this section.

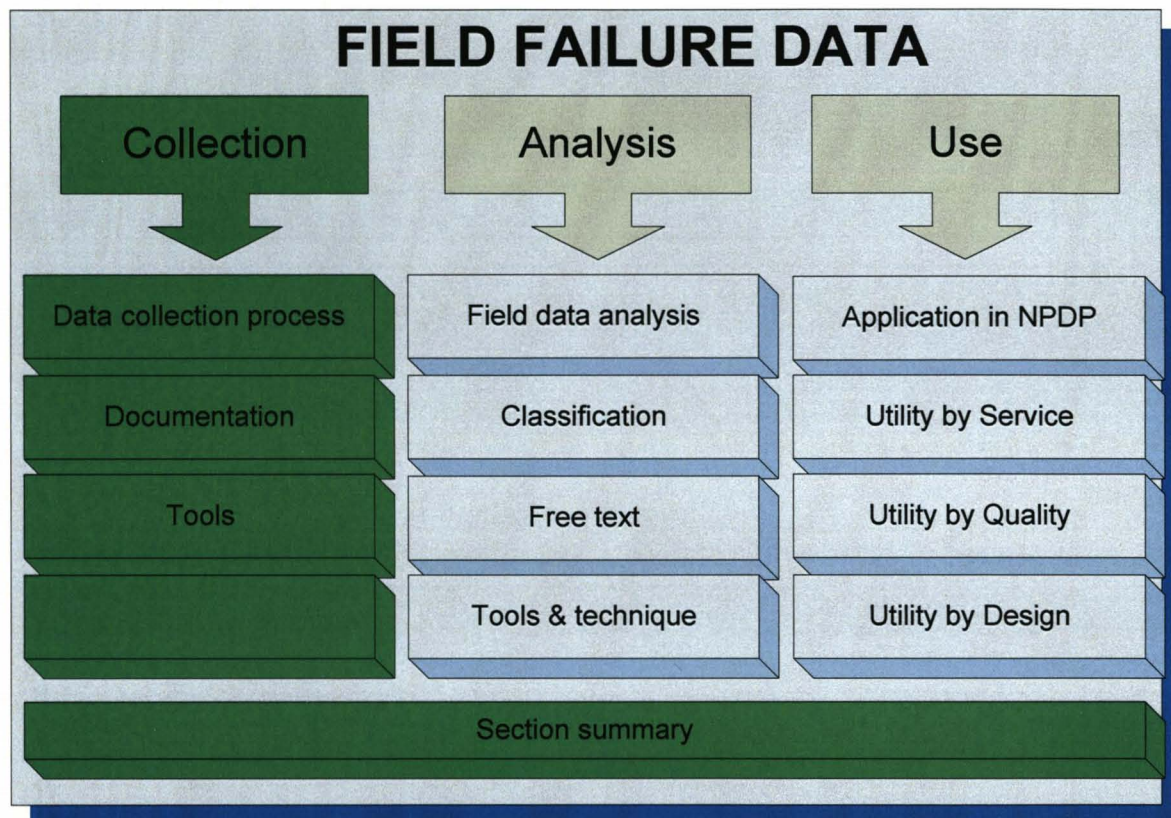


Figure 4-15: Field failure data collection

Field failure data are collected on product-in-use at the customer sites. The service organisation within the case company is formally responsible for the field failure data collection activities. The data collection process begins when a customer logs a complaint to the service call centre about their faulty appliance. The service call centre staff can help the customer either through troubleshooting to identify the problem with the appliance or by providing technical information over the phone or arrange for a local service engineer to visit and solve the issue. The customer complaint is logged on the call centre systems (Op-Tim) and assigned to the appropriate service engineer. The data collected at the service call centre consists of basic information including the customer's description of the problem, name and address and specific product details.

All service engineers within the case company are fully trained on all product models. There are 200 engineers based all over UK, each carrying over 1,500

different spare parts in their customer service repair vans enabling them to achieve a 97% first time fix rate.

During a service call out, more detailed data on product failure is collected from the customer for product maintenance, service or repairs. The field data is recorded in the failure database system which is accessible by the design and quality functional departments.

Interviews with service engineers highlighted that they sometimes receive incorrect information from the call centre staff about the specific customer call out incident. Both customers and call centre perception of the problem is often different to the actual problem the service engineer encounters at the customer site. Fortunately, this doesn't affect the quality of failure data collected, as the service engineers can amend the initial descriptions of the problem on the call centre database to better represent the exact product failure in the field. According to one of the service engineers:

"Call centre staff sometimes do not record information accurately for example, the fault recorded by the call centre may state "boiler leaking" when I get to the customer to confirm the problem, the customer might say no, its hot water not working" (Service Engineer, Respondent N, Transcript 14,p1).

Service engineers use a personal digital assistant system (PDA) for their daily operations. The PDA is a pocket size computerised system which is capable of recording data on failures in the field. The service engineers download, update and close their service call jobs through the PDA. The PDA is used by them to manage spare parts used, van stock, record time on site, record costs on chargeable jobs and capture customer sign off upon completion of jobs. As one of the service engineers stated:

"[All service field activities are now recorded] on the Service engineers PDA. Key functionality of the PDA includes access for service engineers to record real time call information and the ability to manage the calls directly from updates through to completion. Service engineer can access and download their jobs from anywhere they are on the PDA. The call out jobs are uploads directly from the call centre system Optim [which is] used for logging customer complaint" (Service Engineer, Respondent M, Transcript 13, p1).

Failure data collected in the field i.e. from the (customer's site) during service call-outs includes:

- description of the nature of fault
- type of fault, type of component
- root cause of the problem, if known
- effect of the failure
- part changed or spare part used

- action taken to resolve the problem
- gas safety checks

“Whatever we do is recorded on the PDA, it has a drop down box, with a touch screen to access and input all the required information. When you go in to close the job off, it has a drop down menu, where the question boxes give you some options to select from (Service Engineer, Respondent N, Transcript 14, p3).

Service engineers are required to record the problem encountered in the field including the actions taken to resolve the problem at the end of each service call out job, by answering the five questions from the failure database application. This database application is used for recording and monitoring trends of product failure data in the field.

This failure database is different from the OpTim system given that, OpTim is the service call centre application that records basic administrative information about customer complaint. It is also only visible to the service unit and cannot be accessed by other functions within the company. In contrast, the failure database system records detailed information on customer complaint, field problems and actions taken to resolve field problems. As mentioned by one of the service engineers:

“The collection of field data is the failure database system. The service engineers on every call [must] complete the failure database [before they can close a job]. They select a series of options that explains what they have done in the field and [that transform the textual descriptions] which is collated for subsequent analysis by the quality team” (Service Engineer, Respondent M, Transcript 13, p2).

The recording of failure data is encouraged to be completed in real time. However, service engineers sometimes do not record the field failure data immediately after each call-out job. They frequently wait until they acquire a batch of completed jobs at the end of the day. According to one of the service engineers, a reason why fault data is not recorded immediately is because the engineers may be running late for the next service call out, and so they do not want to exacerbate the existing delay. Batch processing often means that the accuracy levels of the information recorded could be jeopardised due to engineers “forgetting” the exact details of service provision.

Service engineers work to predetermined targets and are remunerated based on the number of targets they achieve. An obvious disadvantage of such performance related pay system is that it can affect the quality of the field data recorded as service engineers are driven to focus on their daily targets of six to seven service call outs. Unfortunately, they don’t always seem to value the importance of collecting high quality field data, and as a result too little time is spent on compiling a report about the problems encountered and subsequent action taken to resolve them. For example; a service engineer may describe the fault briefly as, replace faulty parts and fail to explicitly describe the exact details of faulty part which might have led to the malfunction of other related

components. This lack of important detail makes it difficult for designer engineers to identify the actual root cause of a failed component, or the reason why a part was replaced. Design engineers stated that;

*"It is very difficult to identify the root cause of a failure from the recorded field data."
(Design Engineer, Respondent C, Transcript 3, p2*

There appears to be no formalised method for collecting data from the field about product in use failure data. Interviews conducted with the service engineers highlighted that one of the critical aspects of the failure recording process is the need to capture all relevant information relating to the faulty appliance. In certain situations even though the failure is repetitive and already known, it still needs to be recorded. One service engineer uttered the following statement:

*"If we find a repetitive fault, we have to keep reporting it and [raise the issue with the service quality manager, who then launches an investigation as well as inform R&D personnel to investigate the problem before it becomes an epidemic problem]"
(Service Engineer, Respondent N, Transcript 14, p2).*

One of the challenges of the field failure data capture is that the fault code displayed by the appliance does not necessarily represent the specific fault or faulty component. However, in most instances it points the service engineer in the direction of the fault location. Another challenge of failure recording is the inability to record specific fault codes in the PDA, as there is no functional option to do so. According to one of the service engineers:

"The system doesn't allow you to input a fault code. If the PDA is enhanced it could be used to [input fault codes] as well as interpret them. At the moment you cannot put the fault specifically into the PDA unless you put it into free text" (Service Engineer, Respondent N, Transcript 14, p2).

Another service engineer stated;

*"[All the appliances] uses fault code but there is nothing in [Failure database that allows you to record] the fault code. [There should be a list of fault code in the application]. If the boiler displays a fault code, surely in failure database there should be a selection that says FCode, then [the service engineer selects fault code and the system automatically generates problems associated to that particular fault code]"
(Service Engineer, Respondent L, Transcript 12, p2).*

The systems' inability to record fault codes was also identified as a barrier to recording accurate failure data. According to one service engineer:

"The fault codes are fairly good but it would be nice if we could record them more. Also the fault code will sometimes disappear from the appliance so it can't be recorded. Some appliances do have a memory where it would hold up to 3 to 4 fault codes. The customer doesn't often tell you what the fault code is, what the customer tells you is for example "oh my boiler has failed and it was flashing a symbol and I

*reset the boiler”, which is more of a customer error rather than the boilers error”
(Service Engineer, Respondent M, Transcript 13 , p5).*

It is apparent from some of the service engineers' responses that fault codes are important for the process of determining accurate causes of field failures. However, existing failure data recording system does not provide the means for recording such information. Service engineers often have to write fault code details in the free text field.

4.7.1 Types of field failure data

Design engineers were asked what types of data they require from the field and all of the interviewees stated they need more exact and accurate information about a product failure to determine its root cause. 46% of designers agree that design department specifies what product field failure data should be collected by service engineers. The service engineers' protocol stated that they are required to record inventory details such as product type, serial number, model and month in service, in addition to, failure root cause, failure effects on customer and most especially the fault codes assigned at call out. Furthermore 77% of service engineers strongly agree/agree that they are aware that the product failure data is captured for the purpose of future product development whilst 8% are neutral and 15% disagree. However, judging from the inaccuracies and degree of missing information in the failure recording, it might be argued that service engineers do not have an in-depth understanding of the level of detail required by design engineers. There is a need to improve service engineers' understanding of the importance of field data as useful information that serves as a valuable input to the design engineer's process of improving product quality and reliability. This may encourage service engineers to capture more detailed and accurate information about product failures in the field.

One engineer suggested that if service engineers detect a faulty part, they are required to record additional data that answers the following questions - *what is the real problem with the part”? What other parts are affected as a result of this failed part? Is the failure product related or system related?*. As stated by one design engineer:

“We require more exact information such as what is the real problem with the part? Is it only coming from the boiler or from the system surrounding the boiler? In future, we would have predictive maintenance were the product would say “call maintenance”. The product would have an information system, that is capable of calling for support and displaying what is wrong with it” (Design Engineer, Respondent D, Transcript4 , p5).

However another respondent argued that a predictive maintenance mechanism, a sort of integrated health monitoring and management system` is already available in some of the boilers, but this avenue of failure data capture is not utilised, as stated:

“Some boilers have the capability of allowing a service engineer to insert its equipment and download failure information from the boiler? But the information is not stored in the failure database. The downloaded information goes to the laptop of the

service engineer and nothing more. The engineer uses the information to guess why the failure [might have] happened. The downloaded information is only of use to a service technician, the information is not passed on to [the] product development function.” (Service Engineer, Respondent P, Transcript 16, p3).

4.7.2 Fault reporting documentation

Although a formal document (often referred to by the service engineers as the worksheet) is used for the failure data recording purpose, it does not fully ensure the capturing of detailed, accurate and relevant failure data due to human error and mistakes, omissions, misinterpretation of event and vagueness in failure description. 54% of service engineers disagree that failure record gives a true reflection of the problems in the field. Whilst 57% of design engineers agree/strongly agree that field data can be captured in other useful methods such as audio recording of sounds and noises produced by the boiler, video and pictures capture of the failed appliance or components to augment the textual method. This could contribute to capturing information that presents a true reflection of the field problem. However, it is evident that the failure database mainly captures technical information on product failure and lacks contextual information, such as the operational and environmental conditions of use.

This formal document is incorporated in the failure database and Table 4-5 presents one of the excel spread sheets illustrating product type/model, market, fault description, etc.

Table 4-5: Excel sheet of failure database ‘Raw Data’

Appliance	customer fault description	component group	Part	Fault	Fault free written text	Measure Action	Measure Action free written text
277 / VWS geoTHERM C classic /1	06 / Heating does not work	50 / Part/Appliance fault	442 / 3-port valve	051 / Jammed, blocked		05 / Exchanged	
277 / VWS geoTHERM C classic /1	18 / Overheat thermostat operator tripped	50 / Part/Appliance fault	598 / High limit stat	032 / Operation incorrect or disturbed		99 / Other actions	examined without measure
280 / VWS geoTHERM EC exclusiv /1	18 / Overheat thermostat operator tripped	50 / Part/Appliance fault	598 / High limit stat	143 / Fault not reconstructable		05 / Exchanged	
277 / VWS geoTHERM C classic /1	52 / Fault indicated (Display)	61 / Adjustment/Measurement	999 / Other parts	999 / Other faults	Error display	99 / Other actions	deleted
277 / VWS geoTHERM C classic /1	05 / Noises	50 / Part/Appliance fault	746 / Appliance, complete	999 / Other faults	Compressor strong noises	99 / Other actions	examined no ET
277 / VWS geoTHERM C classic /1	06 / Heating does not work	50 / Part/Appliance fault	411 / Additional heater	056 / Short circuit		05 / Exchanged	

All the service engineers interviewed agree that the design of the electronic field worksheet constrains the level of details that can be recorded about the product failure. 53% of service engineers disagree/strongly disagree that the product field failure data reporting worksheet captures all the necessary information about product failure for future corrective action. One of the challenges faced by service engineers for documenting the product faults and repair work they have carried out in the field is that available options for failure description or actions taken are at times unsuitable. One of the service engineers stated:

"Whether you have changed it or repaired it. Sometimes there is no option within the system that best describe the work carried out by the service engineer" (Service Engineer, Respondent N, Transcript 14, p2).

In such situations the service engineer would have to choose the "other" option which requires writing a textual description of events. However there is no standard format for completing this option, the level of details provided varies from one engineer to another. 47% of design engineers disagree/strongly disagree that field data is of sufficient accuracy, furthermore 43% of design engineers also disagree that failure data is recorded in a useful format.

4.7.3 Data collection tools

The main hardware tool used for facilitating field failure data capture is the service engineer PDA. The PDA includes a software application called Geesat, which acts as an interface to other applications such as the failure database. Figure 4-14 below shows the login screen of the Geesat software application.



Figure 4-16: GESSAT System Log-in interface

4.7.4 Failure Database

The failure database application has different fields of coded data where service engineers can enter information by simply selecting relevant options within each field which best describe the faults and the corrective actions to repairs performed.

At the end of every service call, service engineers fill out the failure database answering the five questions presented by the PDA as follows:

1. choose customer reported symptom
2. choose functional group
3. choose affected part
4. choose fault
5. choose action taken

Figure 4-17 below presents a screen shot diagram of the five questions required by service engineer to record raw data on product in use failures. The first screen shows the five questions, the second screen shows an example of available options to select for describing 'customer reported symptoms', once all the questions have been answered, the final screen shows the textual descriptions have been converted to numeric codes. This makes it impossible for service engineers to cross check their inputs and therefore select more appropriate options, if necessary.

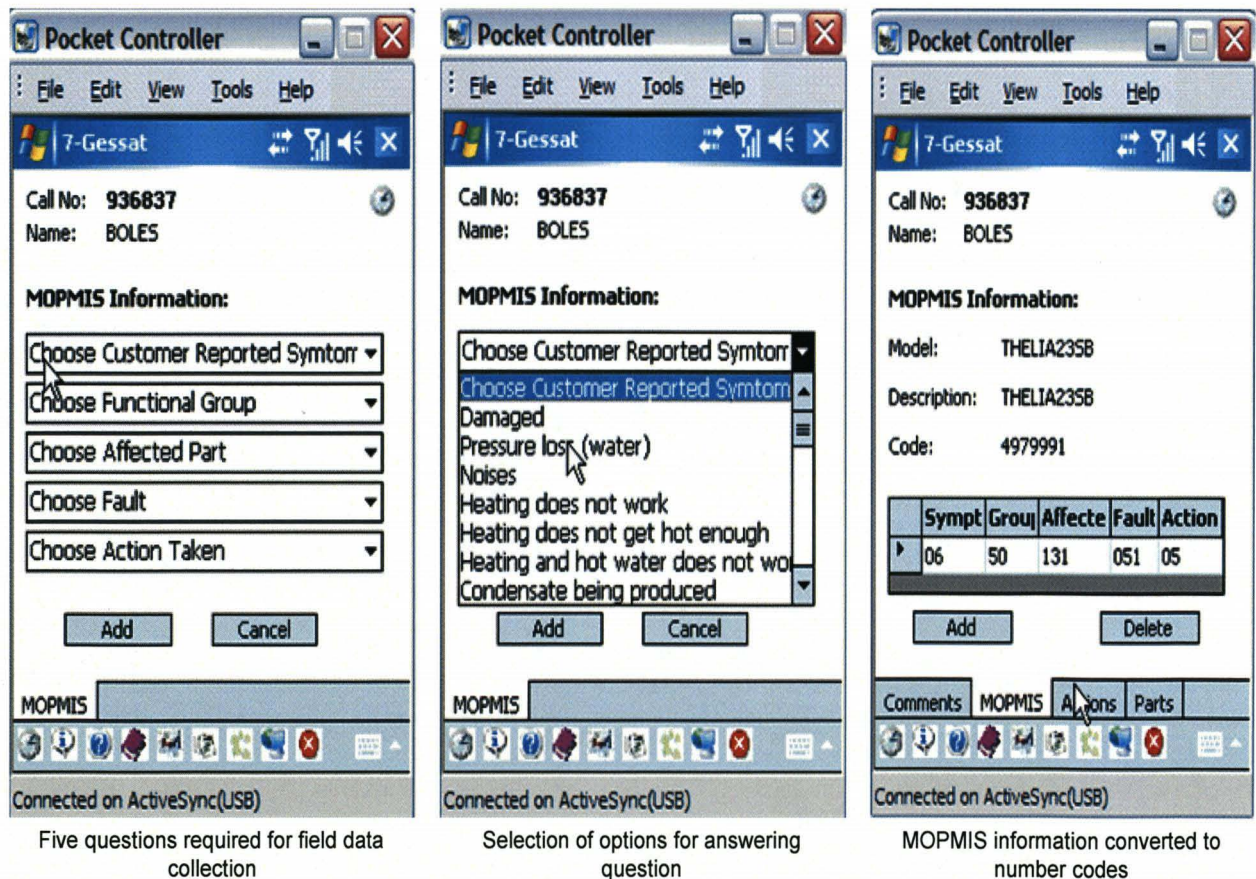


Figure 4-17: Failure database information interface on PDA system

Each of these questions has a listed number of options from which service engineers can choose the appropriate option that best describe the problem encountered. In situations where the required option is not listed, the engineer would have to choose "other" and this requires writing free text to describe the fault or action taken. There are a number of problems with the failure database, which lead one to question the accuracy, relevance, effectiveness and usefulness of its data due to its classification methodology. Service engineers stated that whilst for some of the components, it can be quite straight forward to select the options that best describe the failure and corrective action taken, in most cases they struggle to make this choice. As one service engineer commented:

"[The template for recording information into the failure database] needs to be redesigned; it needs to be more specific. There should be more questions and more options. Because some of available [failure description and failure modes] are very generalised and repetitive. For example if we service a boiler on the failure database there are five drop down boxes, in the first box it will say annual service when you click on it that gives a number, on the 2nd box, it says something on service again. On the third one it says service, and 4th one is maintenance with contract, or without contract and on the 5th is maintenance carried out. So you are sort of repeating" (Service Engineer, Respondent M, Transcript13, p7).

A fellow service engineer stated that:

"There is a need to break down some of the categories a bit more. It might mean more work for us. But I think it might cut out some of the other faults we have to put in. for example giving more detail in the free text" (Service Engineer, Respondent N, Transcript 14, p3).

Service engineers were asked to name three ways the options given by the field failure data recording system can be improved and suggest ways to improve product field failure feedback from service-to-design. The following six themes emerged from the service engineers suggestions on ways to improve options used for recording field data, they are:

- Level of detail - for example, *"it must be non repetitive", and "more categories of failure modes and description list"*
- Accuracy - *"failure description must be accurate"*
- Relevancy - for example *"there must be more relevant selection on the list"*
- Simplicity - for example *"Make fault description very simple and not long winded"*
- Speed - for example *"Make inputting data faster by providing pre-text functionality"*

- Specificity- for example " *Ensure component failure lists is precise*"

Three themes emerged from the suggestions given by service engineers on improving field failure feedback from service-to-design process. They are:

- Communication- for example "*better communication through direct contact between both functional teams*"
- Regular feedback- for example "*[set up] meetings between service engineers and designers*"
- Contextual information- for example "*[capture contextual information on problems in the field by] taking pictures of failed components*"

According to the perspective of the service engineers, failure database is viewed as an application for recording field failure data. It seems that some of the service engineers do not have a thorough understanding of the use of failure database. As the service engineers explained

"[Failure database] is a system that transforms textual information into strings of number which is understood by the R&D engineers" (Service Engineer, Respondent M, N, O, Transcript 13, 14, 15, p7, p3).

Whilst service engineers are unaware of how the field failure data they input into the failure database is presented to designers, they do recognise that it is used by them to identify faults in the field and carry out product improvements.

Failure database is also used for developing R-prognosis (*meaning reliability prediction*) and setting new quality targets for new product development projects. According to the interviews conducted with the R&D quality planner, project leader and CPI leader, there is a common consensus that the quality of data in the failure database is poor. Table 4-6 below presents some quotations on the perspectives of some of the interviewees on the field failure database within the case company. Emerging issues raised based on these perspectives includes:

- Lack of understanding
- Speed and accuracy of the database
- Its incapability to function as required by its users and
- Its usability

Table 4-6: Quotations from different views on failure database

Perspectives on Failure database	Quotations
Design engineers	<p>usability</p> <ul style="list-style-type: none"> “I think the failure database gives us a clear picture on the failure effects but if you really want to know the failure [root] causes you have to investigate further” (Design Engineer, Respondent F, Transcript 6 , p). <p>Speed</p> <ul style="list-style-type: none"> “It is easier and faster for me to ask the CPI team about product failures in the field than to look into the failure database” (Design Engineer, Respondent I, Transcript 1, p). <p>usability</p> <ul style="list-style-type: none"> “The failure database is like an onion, you need to dig deep to get the relevant information” (Design Engineer, Respondent H, Transcript 8, p).
Quality	<p>Speed and accuracy of the database</p> <ul style="list-style-type: none"> “The level of details of data recorded in the failure database; especially in the free text description is a problem” (Quality Engineer, Respondent E, Transcript 5, p4). “Quality of data is poor” (Quality Engineer, Respondent K & L, Transcript 11, 12, p5).
Service Engineer	<p>Speed</p> <ul style="list-style-type: none"> “The database is getting very large and slow to download. When you [examine] the raw data, there is a lot of information that is either not populated very well or doesn’t seem to be useful to everyone” (Service Engineer, Respondent L, Transcript 12, p). <p>Lack of understanding</p> <ul style="list-style-type: none"> I do not understand the use of failure database; I think it is just a system the head office in Germany loves. It is a German system that converts textual information into data strings of numbers (Service Engineer,

	<p><i>Respondent N, Transcript 14, p).</i></p> <p>Its incapability to function as required by its users</p> <ul style="list-style-type: none"> • <i>"Failure database is not capable of capturing all information. Does not allow you to expand on your selected options [that describes failure modes], for example describe all the components changed" (Service Engineer, Respondent O, Transcript 15, p2).</i> • <i>"Inflexible because it is a specific sentence, you can't do any enhancement to it. The number of options you have is not enough and not specific enough to describe the faults of components. Does not give the service engineer that he has reported the fault accurately enough" (Service Engineer, Respondent M, Transcript 13, p).</i>
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4.7.5 Section summary

It is evident that service engineers have the primary responsibility for capturing and documenting the product field failure data. A number of weaknesses have been identified in the current field failure data capture process and suggestions for improvement have also been identified. Field failure data capture is an initial important step in the feedback process from service-to-design. However, the effectiveness of the product field failure data requires a change in the method, tools and format used in data capture process. There seems to be a conflict of interest between operation targets, for example service engineers are keen to meet their daily and commercial targets and satisfy customers by ensuring that their product is functioning as required. Ultimately designers are interested in accessing high quality data that is relevant, accurate, timely and available in a format usable for product improvement purposes. The following highlight the weaknesses in the current product field data collection process as identified in the empirical investigation:

- The current service-to-design feedback process only captures component related failures and does not capture contextual data such as the environmental conditions related to how the appliance is operating e.g location.
- Service engineer's motivations are focused on meeting their daily target instead of recording high quality data, which is both relevant and subsequently useable by designers.
- Service engineers are often not sure of the root cause of a fault and so only record effects and symptoms of failure.
- Options given by the system to record failure information are sometimes not sufficiently adequate to describe the actual fault experienced by the service engineers.
- Service engineers are limited to only select one option to represent their product field failure. If this is insufficient they are required to use a free text input regarding faults or actions taken to resolve them. The textual

description is often difficult to decipher given the variation in service engineers' interpretations of what has led to product failure, use of terminologies and abbreviations. There is a discreet lack of standardisation in this activity, making the link to failed components a difficult exercise.

- The data capture process focuses on general fault information and less attention is given to specific details.

4.8 Field failure data analysis

Once the failure data has been captured from the field, the next step in the feedback process operation is to extract relevant and useful information out of the failure database and analyse it. This section will discuss the analysis of the field failure data at the case company as illustrated in Figure 4-16.

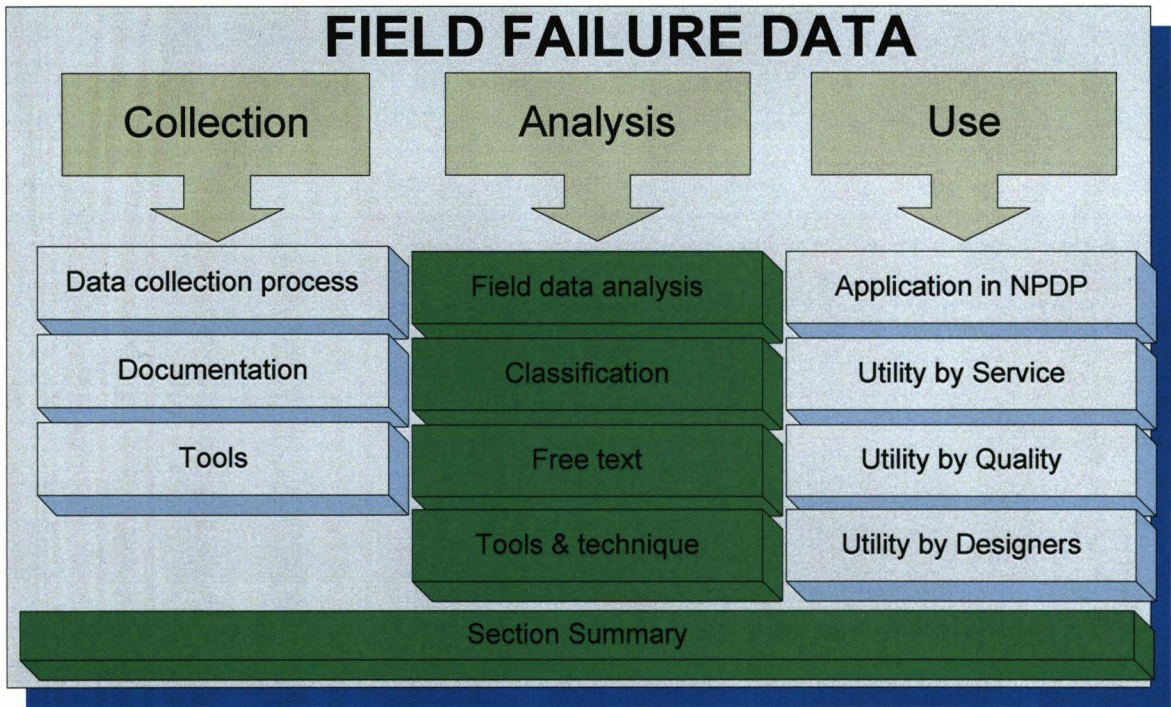


Figure 4-16: Diagram illustrating “Analysis” discussion points

The analysis of the field data is ultimately concerned with determining the root causes of failures. They are incorporated into the new product development project in order to prevent identified failures from reoccurring. 43% of design engineers disagree/strongly disagree that root causes of product failures are identified and recorded by the service engineers whilst the same percentage of design engineers agrees that root causes are identified and recorded by the design team. However 77% of service engineers agree/strongly agree that they identify and record root causes of failure in the failure database. In contrast the interview findings indicated that service engineers often records the effects and

symptom of a failure and not the actual root cause. Further understanding can be generated from the field data analysis to focus the attention of the development team on either improving existing product design or processes or both. It was evident in the interview data that great emphasis was made on the current quality of data that is captured which makes the analysis difficult and time consuming. Design, quality and service engineers agreed that in order to analyse the failure data effectively, greater levels of detail are required from the field. If the data collected is sufficiently accurate and detailed for use, 77% of service engineers and 61% of design engineers agree/strongly agree that the failure data will allow for subsequent analysis of reoccurring problems across product families.

Service engineers lack understanding and appreciation of the subsequent value and use of the product failure information they capture from the field to design engineers. This might be because of their little or no involvement in the analysis of the field data. 54% of service engineer disagree/strongly disagree that they get involved in the analysis of the field data. Capturing relevant data in the future will demand this situation to be corrected, as it will improve their understanding of designers' requirements for quality field data.

4.8.1 Classification

Improving product quality and reliability requires data to be classified in a way that allows for easier manipulation for extraction of relevant information and ensuring the quality assessment of existing products so that corrective actions are assigned for future product improvement. It was highlighted in a previous section on failure database that one of the ways service engineers would prefer to capture data is through better failure categorisation by having more simplified failure options enabling them to record more accurately actual events and corrective action taken. 61% of service engineers disagree/strongly disagree present classification of failure option is adequate for characterising product failures in the field whilst 67% of design engineers neither agree or disagree if existing classification of failure modes are appropriate.

The current method of data classification in the failure database is not sufficiently effective for service engineers to accurately describe the specific problem situation they are faced with. The options available in some of the fields are repetitive, irrelevant, missing and sometimes consist of unfamiliar terminology. The problem is that the failure data classification makes it difficult for service engineers to record data about product failures accurately. On the other hand, both quality and design engineers find it difficult to extract the relevant information. As stated by a design engineer:

"If the failure record has too many details, you don't find the highlights of the failure. If it is too abstract you don't find the failures. In between this balance there is a limitation and a need to get the relevant information out of the field data" (Design Engineer, Respondent C, Transcript 3, p7).

The large listing of menu options for failure descriptions are cumbersome because some of them represent similar problems, some of the codes are described too vaguely and others need a further break down with a more specific fault description. The resultant effect of the larger listings or categories of fault description is that service engineers sometimes get confused with which fault

description best describes the problem at hand. It was suggested that the sub-menu needs to have more options, the categories of failure description needs to be expanded to be more specific wherever possible. The following service engineers' comments emphasise this issue:

"The number of options you have is not enough and not specific to describe the components failure mode. Sometimes when I am clicking and filling boxes, I feel it is not quite right. The options are sometimes not near enough to give the exact problem and action taken. I often have to choose options that I think is near enough to describing the fault. It is I a multiple choice of options but there is not one that is exactly right." (Service Engineer, Respondent N, Transcript 14, p9).

"If you were to ask me [service engineer] for all the jobs I did yesterday, and say for example you requested for information about a job that has a fault code, I wouldn't know because of the way the system works. It is so unspecific I can't remember, if it was more specific I would be able to remember." (Service Engineer, Respondent N, Transcript 14, p9).

4.8.2 Importance of classification

A better failure differentiation method is required that would enable service engineers to make explicit decisions about which component caused the failure (root cause) as well as the failure effect. Presently a service engineer may record a failure as "broken pump" and not state why the pump is 'broken'. When the pump is sent back to the supplier, the investigation carried out by the supplier may confirm that whilst the pump is broken or not performing, it is not the original or root cause of the component fault. After further investigations by the R&D team, it could be discovered that the problem is as a result of other systems working in conjunction with the component, for example, dirt in the water flowing through the boiler pipes or pumps could cause the pump to become blocked and not perform to specification. As service engineers sometimes do not capture the root cause of a failure, the data collected is not entirely useful to the design engineers. Further investigations often have to be conducted in order to identify the actual cause of the failure, which is a time consuming process. As stated by a design engineer:

"I think the failure database gives us a clear picture on the failure effects but if you really want to know the failure causes you have to investigate further to find out what is the actual cause of the problem." (Quality Engineer, Respondent F, Transcript 6, p5).

Determining root causes of the failure would make it easier for a person to understand why a component failed. Information about root causes is important to determine the impact of the failures on the overall product reliability.

All of the respondents from the service questionnaire strongly agreed that there is a need for better classification of options in the failure database application. This could aid them in diagnosing the faulty components in order to identify the root cause of the failure mode.

4.8.3 Free text

A major problem with the data classification is created by the free text option, which is used for providing further details on component failure. The large listing of existing failure descriptions makes service engineers unsure of which field to insert a text with explanation. If the option that best describes a fault is unavailable they need to input this information as free text. The problem with writing in the free text space is there is no standard format, and so the content of the free text varies, whilst some service engineers write at length others may only give brief comments which are subject to misinterpretation or the need for more details. Some engineers tend to stick to the set menus provided by the system, because free text provision is time consuming via the handheld PDAs. As mentioned in previous sections, information on fault codes is important to the R&D team for analysing the root cause of the failure but since there is no special facility on the failure database to record the fault codes, service engineers tend to enter this piece of very valuable information in the free text option. About 95% of the respondents from both the design and service personnel mentioned that the fault code is often not recorded. It was also generally agreed that it is difficult to interpret data input via free text option. As stated by a respondent;

"A service engineer can input damaged in the free text option and that could mean anything. [it is important to explicitly define or describe what is meant by damaged) for example what does he mean by damaged- is it broken, is it leaking, corroded etc." (Design Engineer, Respondent D, Transcript4, p4).

An explicitly written free text is more important to designers because it gives them a broader and better understanding of the problem circumstances including interventions and any replacement parts. The challenge for the case company is to encourage more engineers to write some additional information in the free text option.

The yellow shaded parts of the table in table 4-7, highlights an example of free text provided by service engineers in circumstances when the option "other" is selected when recording failure incidents from the field.

Table 4-7: Example of free written text on field failure

Appliance	Customer fault description	Componentgroup	Part	Part (free written text)	Fault	Fault (free written text)	Measure Action	Measure Action (free written text)	Measure free written description
199 / VC ecoTEC exclusiv	52 / Fault indicated (Display)	71 / Display (information)	984 / Display		999 / Other faults		99 / Other actions		Display F-22 pump (Grundfos) exchanged, wedges, blocked
199 / VC ecoTEC exclusiv	03 / Damaged	50 / Part/Appliance fault	999 / Other parts	Burner flange	006 / Damaged		99 / Other actions	renewed	Luftansaugrohr exchanged; Burner flange renews;
199 / VC ecoTEC exclusiv	52 / Fault indicated (Display)	71 / Display (information)	984 / Display		999 / Other faults	F23	99 / Other actions	F23	Display F23; PWT cleaned; Air-separator-cleaned; Exhaust program after filling
199 / VC ecoTEC exclusiv	52 / Fault indicated (Display)	50 / Part/Appliance fault	971 / NTC - return		032 / Operation incorrect or disturbed		99 / Other actions	additional grounding attached	NTC - Return additional grounding attached;
199 / VC ecoTEC exclusiv	08 / Heating and hot water does not work	50 / Part/Appliance fault	746 / Appliance, complete		999 / Other faults	Error not comprehensible	99 / Other actions	VC adjusted	Equipment, completely VC adjusted; Clarifying of attitude cascade does not z.Zeit possible.
199 / VC ecoTEC exclusiv	06 / Heating does not work	50 / Part/Appliance fault	746 / Appliance, complete		999 / Other faults	no error ascertainable	99 / Other actions	examined (without measure)	Equipment, completely examined (without measure);
199 / VC ecoTEC exclusiv	19 / Appliance switches to fault mode	71 / Display (information)	984 / Display		999 / Other faults	Attitudes kompl	99 / Other actions	Examined	NTC - Advance examined; Display examined; Manometer sealed; NTC - Return examined;

4.8.4 Analysing the field failure data

The analysis of field failure data within this case company is the responsibility of the quality engineers, in particular the quality planner. Design engineers do not get involved and so lack experience in analysis and subsequently find it difficult to decipher field data in the database for making design changes. Therefore they liaise with the continuous improvement team on a particular product development project to explore failures and potential solutions. The continuous product improvement (CPI) team make regular use of field data; they are also involved in the data analysis. According to a design engineer:

"It is difficult for the design engineer to interpret the field data. The failure database is available on the intranet; however it is impossible for the design engineer to look beyond the data. Unlike the continuous product improvement team, they are constantly updating the database and make use of the database for failure analysis and product improvement" (Design Engineer, Respondent B, Transcript 2, p5).

Failure data analysis is done on a monthly basis, and a report is produced at the end of each analysis period. In every product development project there is a quality planner who is responsible for interpreting failure data and providing the failure data analysis report for the design team. To elicit value from the failure data analysis, it needs to be organised in simple clusters, summarised and interpreted for use in new projects. Basic filters in the failure database where the raw failure data is stored are used for splitting the data into different market, modules, parts and components. One of the design engineers stated:

"There are so many lines of data; it is currently difficult to extract [relevant] information out of it" (Design Engineer, Respondent I, Transcript 9, p5).

"For each project there is a quality person in the team and one of their duties is to do the forecast, which is the failure rate forecast for the new product" (Design Engineer, Respondent H, Transcript 8 , p3).

4.8.5 Tools and technique for data analysis

The failure data analysis involves examining the highest number of failures for each product line. This failure data is compared with each other and prioritised to identify the biggest impact on the product and for the company. Once the team have an idea of how to solve the problems identified, an investigation is conducted to generate potential solutions. The potential solutions are then tested during the field test. If the potential solutions are confirmed to be successful, it is either implemented in the appliances or through the service kit. Service kits are parts used by service engineers in the field to resolve a known problem by replacing the faulty component with the service kit.

Reliability testing is another method used in the company for analysing the failure data. The outcomes of such tests have a strong impact on the reliability prognosis which is used in forecasting the failure rate of new products. One of the major challenges of field failure data analysis is the lack of access to information about part failure history. There is no link to historic data on failed parts, which could help in understanding the failure and making better decision on how to resolve the problem. This would also reduce time used for finding appropriate solutions to a specific problem. Some failures are given a higher priority for example, faults in gas supply and other safety related failures. A major technique used for prioritising the failure data is Pareto analysis. The Pareto chart is used to graphically display failure data in several clusters to show the frequency and volume of failure modes. Quality targets can be achieved via Pareto analysis by prioritising some faults over others to identify the highest volume of failures for using subsequent cluster analysis, in order to identify the highest number of failure reoccurrence. One of the quality engineers defines the Pareto analysis as follows:

"Pareto is the number of possible faults we could have in the future, so seeing a high percentage of problem in the field, we can estimate that if we work on the highest percentage, the problem will be less in future. In that case that saves money for the company as well the amounts of work we have to do for fixing the problem" (Quality Engineer, Respondent E, Transcript 5 , p3).

The following statement as mentioned by one of the design engineers describes how the Pareto analysis is monitored:

"We monitor the first 80% of failures. The first 80% would be monitored, corrected or changed. And we check the database for changes. Sometimes it may not change in some cases only missing information from the field" (Design Engineer, Respondent H, Transcript 8, p3).

This technique helps in deciding the courses of corrective action that would give the biggest benefits. The diagram in Figure 4-17 gives an example of a Pareto chart analysis of the U.K XI product range. The Pareto chart will enable the quality planner and CPI team to focus on the most critical aspect of the product failure on which to concentrate.

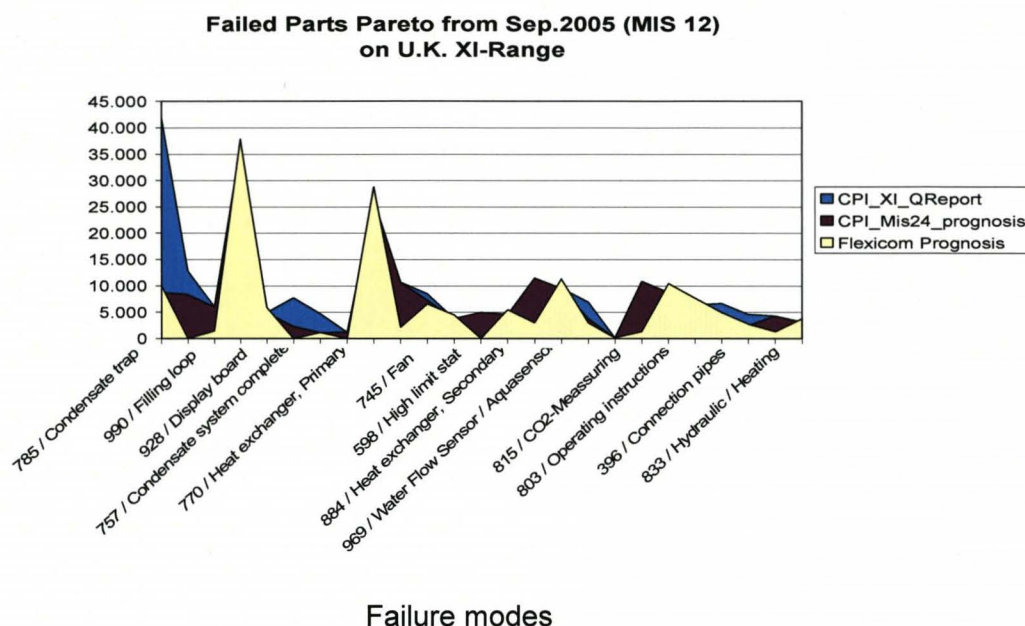


Figure 4-17: Example of Failed parts Pareto chart

Sometimes there are low-volume failures which occur at regular intervals and are more predictable. One of the interviewees mentioned that because the Pareto chart highlighted a faulty component that was regularly replaced, that doesn't necessarily mean there is an inherent problem. Further investigation would have to be conducted to finalise if it is actually a problem or not, and to identify the level of priority that should be assigned to it. Priority levels can be raised if applied when failed components do not fail within legal and regulatory requirements. The highest level of prioritisation is given to faults that have safety implications that might become hazardous. For other minor, less impactful faults, prioritisation is low.

According to one of the quality engineers:

"The amounts of work you have to do for fixing the problem also determine how you prioritise the task. For example, if we know an appliance will be replaced by a new one the following year, we do not save [focus] on this small problem, and we consider it to be a problem for the next project. If the component problem is a smaller problem with less impact we would concentrate on other problems which are bigger and more important with longer life time" (Quality Engineer, Respondent E, Transcript 5, p3).

As stated by one of the respondents the longer a component is running within a product series, the lower the failure rate. This is because of the various improvements that would have been done to the parts over the period of producing the product series. It was also reported that the number of exchanges carried out with regards to a specific part does not indicate there is a high volume

of problem with that particular part. The replaced part may not be the root cause of the failure; rather it may have been a symptom by the actual failure root cause. As mentioned before, the service engineer often changes more than one part until a problem is resolved. Another reason why some faults receive higher priority over others is when there is a large volume of personal complaints by the service engineers; this information is often not recorded in the failure database. As mentioned by one of the respondents;

"There is a community on the intranet where service engineers and their supervisors can make comments on appliances based on their experiences in the field. If there is a common complaint which a lot of people [have reported] then a colleague [is assigned] to carry out further investigation on that particular complaint" (Service Engineer, Respondent O, Transcript, p4).

4.8.6 Section Summary

The following are the key learning points to summarise field failure data analysis discussions

- The large range of failure modes makes it difficult to extract relevant information about true causes of product failure from the failure database.
- Field failure data input have no links to historic data of similar failure modes with similar products/families.
- It is time consuming to evaluate the data because it often requires more detailed analysis in order to identify the actual root cause of a failed component.
- The failure database consists of data from only two major markets which are Germany and UK. Product failure data from other markets such as France, Spain, Italy, and Skalska are missing. This makes it difficult for design engineers to compare similar components from different markets.

According to a design engineer:

"There should be data from the different market. Especially markets where large amount of appliances are sold such as Italy, Spain. That would be very helpful [for comparison of failure modes]. The reason why data is not available from these countries is because they have different organisations. To gather all this data, it would cost a lot of money. They would have to create an organisation that takes care of the installers, organisation that monitors the installers, collect all this information, record them into the common database. This cost a lot. That is the reason why we have it in few companies" (Design Engineer, Respondent B, Transcript 2, p8).

- Free text fields cannot be filtered and it is difficult to extract relevant information from the free text because of the variance in the level of details provided by service engineers.
- Quality of the data is poor

- Available options of diagnostic purpose are not often specific to the problem which service engineers resolved.
- Not capable of capturing all information, for example if an engineer changes more than three components in a boiler, the engineer can only input data on the main components failure, other information relating to the other two component cannot be recorded.
- Classification of failure data is difficult to understand, which makes it difficult to easily represent and identify problem areas that need improvement.
- Lack of contextual information such as operating environment of the appliance that might help in understanding why a particular component has failed.

4.9 Field failure data use

This section presents how the outcomes from the data analysis are used within the product development for the purpose of improving product quality and reliability. Figure 4-18, shows the discussion map which highlights the key points of discussion in this section.

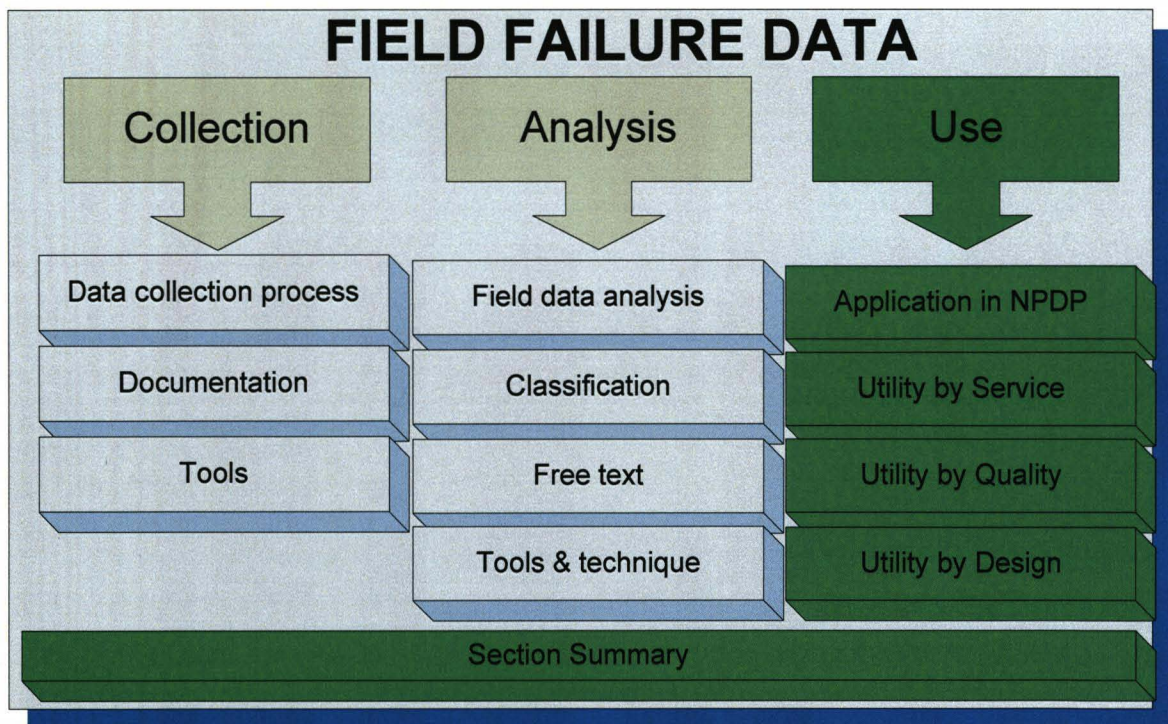


Figure 4-18: diagram illustrating "Use" discussion points

4.9.1 Application in new product development process

Prior to the start of a new product development project the history of similar product failure modes is required and determined by cross checking the field data and failure rates and product performance. Field failure data is an important

input at the beginning of a new product development project especially when customer requirements are being transformed into a design specification. Field failure data is required during the technical requirement specification phase, where the reliability prognosis of product failure rate is made, so that quality targets can be set to improve product quality and reliability. For every product development project, there is a set target or acceptable quality level (threshold) for the failure rate for appliances (boilers) manufactured. Field failure data is also required for test planning during the concept stage and generally serves as inputs for writing requirements for new products. As one of the design engineers states:

"Before we start a project we go into the raw data to collect field data. We are asked to do a reliability prognosis for the new development. Because we are responsible for the quality figures and we have to improve them, therefore part of our task is to do the continuous product improvement in our department and we have to reach our target level to define quality for the product itself" (Design Engineer, Respondent G, Transcript 7 , p4).

To support this statement 90% of design engineers agree/strongly agree field data is useful input to FMEA of which 43% agree/strongly agree that it is currently actively used in the FMEA process. In addition, the experience of transferring this failure data into the FMEA process is essential for making realistic estimations of the possibility of occurrence, detection and the severity of the failure modes. However service engineers level of understanding on FMEA is limited. 46% of service engineers disagree/strongly disagree they have a good level of understanding about FMEA. This inevitably makes it difficult for them to know what amounts to relevant field data capture for the FMEA process. This is further supported by 62% of service engineers who replied neutrally regarding their knowledge of useful data input to the FMEA.

Field data highlights problems in the field which are used during the FMEA process for identifying the potential failures that can occur in a product before it reaches the customer, so that such failures can be prevented. In some cases despite the fact that changes are made to product design, other problems still occur in the field. According to a design engineer, problems that occur in the field are potential failure modes that were not identified during the FMEA process.

"There is no systematic [process] at the moment, very well known problems are used in the FMEA, no one will forget to put the well known failures into FMEA but the small problem can easily be forgotten and not included in the FMEA" (Design Engineer, Respondent C, Transcript 3 , p3).

Although product field failure data serves as a valuable input to the FMEA process, 45% of design engineers indicated that whilst it is readily available for use, 43% suggest it is not recorded in a useful format. However in practise, it therefore appears that the link between field data and FMEA is not fully exploited. By way of improving integration, one might link field data directly to the occurrence evaluation in an FMEA process. The following quality engineer's comment illustrates some scope for such a link:

"At the moment there is no link between FMEA and field data. The link exists only in the mind of the FMEA session participants. At the moment, when we develop a new product, I then discuss with the project leader about the current problems" (Quality Engineer, Respondent J, Transcript 10, p).

The lack of effective process management and responsibility in the present organisation's operation means that there is a need for roles and responsibilities for collecting the failure data and translating the field experience into the FMEA process. In other words, the effective application of field failure data in the FMEA process requires experience and knowledge of the product in combination with detailed information of the failure root cause. According to a quality engineer;

"Field data without root cause of the failure doesn't make any sense. Root cause of a failure is needed to consider the failure in FMEA then you have a link between both" (Quality Engineer, Respondent K, Transcript 10, p3).

The service engineers interviewed agreed that the current system setup makes it difficult to have a detailed level of description of failure causes. According to one of the quality engineers:

"The system can be improved but with the current system it is impossible to get to it, because the service engineer has to select and choose the failure code and normally he is a little bit limited in what he can choose, what he can provide and how deep he can analyse it. I think the failure database gives us a clear picture on the failure effects but if you really want to know the failure causes you have to investigate further" (Quality Engineer, Respondent F, Transcript 6 , p3).

Solutions to field failure problems helps to improve product design outcomes, provided they are available in a timely fashion, otherwise they become concerns for new generations of products.

"Field failure data helps us to improve current series of product design and new generation product design. It depends on the mass of changes that you have to change. When it is a minor change then we make it as an improvement but when we have bigger change then we have to wait for the [development of] new series of [the appliance] and then make new design. Then you have an impact on product design" (Quality Engineer, Respondent J, Transcript 10, p4).

- **Cross-Market Integrative Analysis:**

A challenge for the case company is to obtain data across different market segments, as this would enable more comprehensive comparative analysis of product performance and failure rates. In UK and German markets, the service organisation is owned by the Vaillant Group, whereas in countries such as Italy, Spain etc, the service organisation is outsourced to external agents, therefore the monitoring of failure data is not an integrative or uniform activity. As stated by one of the interviewees,

"It would cost a lot of money to create in-house service organisation in all the market"
(Design Engineer, Respondent B, Transcript2, p6).

It can be argued that while the organisation is trying to save costs from having an in-house service organisation, the cost of improving product quality and reliability would be extremely high because failure data is not easily or readily available. A great deal of time, money and resources is spent in investigative research and analysis to resolve problems in the field. The methods of collecting field failure data are quite different across all markets; there is no standardised data collection or failure feedback method. A majority of the interviewees agreed that standardisation is very important to allow comparisons of product performances and field failures across markets.

4.9.2 Utility by service

In order for the field failure data to be utilised by both quality and design engineers, it is essential for service engineers to capture and document quality data that gives an accurate representation of the actual performance of the products in the field. It is also important for service engineers to be aware that the quality of field data capture will affect the decision made by the designer when making changes to existing or new product generations, which overall will have an effect on the quality of the product and customers' satisfaction.

4.9.3 Utility by Quality Engineers

It is the responsibility of the quality planner to make use of the field failure data analysis produced by the CPI team to perform fault prognosis and set quality targets for subsequent new products and monitor quality improvements. The field data is used for assessing the occurrence of the failures and current quality of functionality of products in the field. For example, if there is a problem with missing sealing, the first step is to monitor the failure rate, how often does the failure happen? Is the problem occurring in a particular product model? Questions of this sort are presented in order to identify the scale of the problem and the level of action required to resolve the problem. Quality planners also work with the design team to generate ideas and solutions to improve the products. According to one of the quality engineers:

"The quality target may not be achieved in the first instance but it is constantly revisited throughout the product development process until the desired quality target is achieved" (Quality Engineer, Respondent K, Transcript 11, p4).

- **Utility by Continuous product improvement team (CPI)**

Field data is used for monitoring failure rate. The continuous product improvement (CPI) team is responsible for monitoring products with the highest failure rates and discussing how they can be reduced. This is done by assigning failure modes to an individual or team with relevant expertise to carry out further investigation to generate the necessary solutions and how to implement them, hereby preventing them from reoccurring.

4.9.4 Utility by Designers

Field failure data is required as early as possible by designers in order to assess how similar components or products are performing in the field. This information aids the designers in making changes and improving on the existing product functionality. However, current limitations of the field failure data collection process means that early service feedback is not often possible. This is due to the fact that it can take up to one or two months before a failure trend and feedback is identified. As mentioned by one of the design engineers:

"Getting early failure feedback depends on early monitoring and service sensitivity to the failures in the field" (Design Engineer, Respondent, Transcript, p4).

Product field failure data is used by the designers during the FMEA processes as input for identifying possible failure modes that might occur in an appliance. Output from the FMEA process influences the new design or improvements made to existing products. 54% of the service engineers are aware that field data is captured for the purpose of future product improvement. However, in order for this to happen all the design engineers interviewed agreed that more exact data on product failure is required from the field, for example "is the problem from the actual boiler or from the system surrounding the boiler?". It was reported by design and quality engineers that not all failures are component related, product failure sometimes occurs as a result of the product interaction with another part of the system within which it operates. For example, 50% of the flow sensors sent back to R&D are recorded as faulty PCB on flow sensor, but in 95% of the cases when the returned parts are investigated it was identified that the PCB's are faultless. This means that the reason for the intervention and part-replacement by the service engineer was different to what he actually recorded. Therefore, there is a loss of vital details in the field failure data recorded by the service engineers. It is evident that there is a need for re-educating the service engineers on the importance of capturing more accurate information so that is useful for the design engineer to make improvements to product. Closing the communication loop, that is creating the ability to translate and transfer the failure data into useful knowledge. Types of failures and failure rates in the field are well known, and real organisation and management challenges reside in how well the data is transformed and incorporated into new product designs to reduce future field failures.

At present the field failure data collection focuses on product failure at the component level. In situ data capture recognises the importance of the service engineer in capturing rich information on the environment in which the product operates, contextual information on how the customer uses the product and the customer's perception of the product quality and reliability. In addition to the textual description of the failed component, capturing data in situ might be enhanced by taking photographs of failed components and unusual situations or product condition of use and capturing information on the status of the boiler before it failed. Lack of information capture on data in situ is an area where vital information for product improvement is lost. This data could improve the understanding of as to how a component failed and also the customer's expectation from the product.

- **Obtaining addition information**

In situations where the root cause of a failure cannot be easily identified, design engineers often request additional information to augment the failure database. In the interviews conducted with design engineers, the need to identify the root cause of a failure was often highlighted. One of the methods used for investigation of the root cause of a failure is to obtain further information from service engineers on what might have been the actual cause of the problems in product performance at the customer site, and what were the steps taken to resolve it. In some cases, in addition to the general recording of field failure data on failure database, service engineers are issued with pro-forma and are instructed to complete them as additional information. The pro-forma sheets are used to capture information not recorded in the failure database. This information is used by R&D to extrapolate the root cause of a problem.

"If someone in the design or R&D department takes an interest in a fault, they would send us a pro-forma to capture more information, which is hand written and the appliance might be specifically packaged and sent to the person." (Service Engineer, Respondent M, N, O Transcript 13, 14, 15, p10, 1).

- **User friendliness**

It is evident from the interviews that the user friendliness of the field failure data depends on the user's expertise and frequency of use. 41% of the design engineers neither agree nor disagree the mop-mis failure database is user friendly, this may be a result of their irregular use. For example, fifty percent of the interviewees appeared to be occasional users who only consult the database if there is a need for it. This is because in every product development project there is a quality planner whose responsibility it is to interpret the field failure data. Although the failure data is easily accessible by anyone within the organisation via the intranet but, as stated by one of the interviewees:

"It is difficult for design engineers to look beyond the data" (Quality Engineer K, Respondent, Transcript 11, p1).

There was a general agreement that the field failure data provided is incomplete and missing vital information such as the root cause of a failure. This makes the data less user-friendly and difficult to use because further investigation would have to be conducted to fill the missing gap and make it useable. According to one of the respondents from R&D quality planning;

"The field failure data is a big list. In order to make the analysis or know the root cause of the failures, you have to spend some time analysing it. It is difficult to use the field data. If experts in the laboratory are showed the failure they often know the root cause, for non-expert it is difficult. I think it needs to be improved but I don't know how it can be improved" (Quality Engineer, Respondent A, Transcript 1, p5).

The ambiguity of free text also makes the data not user-friendly. In addition to this, the large volume of data makes it difficult to manipulate the data and extract

relevant information out of it. For example, it is easy to identify problems with a high failure rate but difficult to identify single failures. To achieve the latter, prior experience and knowledge of the product as well as the failure modes is required.

- **Physical assessment of returned parts**

The facility to collect all possible further information about product failure is important; otherwise the designer is only able to filter the failure database for information on a specific part. Designers sometimes request for field parts returns in order to analyse and identify the fault with the failed component. Having access to the intervention number is also useful for analysis. The intervention number is written on the package in most cases.

"All the faulty parts that we remove that are faulty are sent back to R&D, we have a little piece of paper, where we have to write down the job number, we can put a tick box and brief description. That in a way, you can determine, not fault in appliance as a whole but faults in the components you sent back" (Service Engineer, Respondent 0, Transcript , 1p).

- **Timeliness of field failure data**

It was generally agreed by the respondents that the availability of field data is good but the timeliness and speed of having the right field data when required depends on the type of product. For example, if it is a new product with new technology and a special telephone hotline, the feedback will be relatively quick. Hotlines are special telephone numbers that link directly to designers after the launch of a highly innovative product, so that service engineers can communicate directly with them about any problems they are experiencing in the field regarding a specific product.

Preventing existing field failure modes from reoccurring in new product design can also depend on the timeliness of design engineers obtaining feedback on product performance in the field. For example, according to one of the respondents, field failure data is not always easily accessible for service engineers. In the case of collecting special information e.g. the level of corrosion inside the appliance and the content of the heating system, a special software programme for data acquisition may have to be installed in the system in order to capture this information.

- **Quality of field failure data**

The quality of field failure data was considered insufficient for design engineers to substantially improve the quality and reliability of new product design. The quality of FFD collected can affect the decisions taken during design because the design engineers have no accurate understanding of why a component has failed. This might be because of the incompleteness and ambiguity in the free text written by the service engineer to give further detailed description of the problem issue and what was done to resolve the problem. As stated by one of the respondents interviewed:

"You have to know what is really behind the failures. To use the field failure data you have to go deeper in the analysis if you really want to detect the actual failures causes. Very often the service technician only records the effects and not really the failure causes. For example, a customer complaint about noise, so what is the reason for the noise, what are the relative causes" (Quality Engineer, Respondent, Transcript1, p1).

4.9.5 Limitation of the research methodology used

The use of five point Likert scales responses in the questionnaire survey has a number of disadvantages for example; respondent could avoid using extreme response categories. The five point Likert scale may have prevented the respondent from giving more specific answers because responses from the questionnaire appear to be more neutral response. The selection of neutral shows an inconclusive result. Although a follow up interview was conducted with some of the questionnaire respondent in order to clarify some of their responses. The author could have used a different scale of measurement that would have force the respondent to give more specific answers. For example by removing the neutral option, the respondent can only give either a positive or negative answer to questions and avoid sitting on the fence.

Although questionnaire surveys provide insight into the existing feedback process practise, they might raise a certain bias because of their self-reported nature. For example bias could be raised through the authors selection of questionnaire respondents. Participant of the questionnaire survey from the design and quality unit were limited to personnel that were interviewed. This was done in order to triangulate some of the data gathered from the interview survey. However, a larger sample of design and quality engineers could have been contacted to participate in the questionnaire survey. Both questionnaire and interview data were used for triangulation in order to ensure the validity of the research. Once relevant data had been identified from one source of data its significance was then confirmed through the use of the other data sources such as the company's documentations which were relevant to the feedback process. These documents were used for cross-checking what respondents said and reported.

4.9.6 Section summary

The field feedback process operation has been classified into three main aspects which are capture, analysis and use. It is evidence from the exploratory investigation that service engineers are solely responsible for the capturing of failure data from the field, whilst the quality planning engineers are responsible for the analysing and making sense of the data so that it can be presented in a useable format for design engineers to use in new product design.

4.10 Chapter summary

This chapter has addressed objective two of this thesis, namely to empirically inform theory to develop a framework for field failure feedback that better integrates service and design functions.

Deficiencies in the case company's existing methods of obtaining field failure feedback were identified at the level of generic process and data. A clear need to obtain field failure feedback process using discrete operations, managed to deliver future product improvements was articulated. This process extends from service engineers working in the field to design engineers in the office, whilst incorporating a quality engineering role.

In terms of field data, much needed to be resolved to ensure the quality of data captured by service engineers and the levels of standardisation deployed. Classification challenges made it difficult to represent true events in the field. Furthermore there is little capacity to connect field failures to past events to obtain a rich picture for FMEA and subsequent root cause analysis. In general, there appeared to be a lack of integration between the service and design functions, curtailing a better understanding of product-in-use. The empirical case study findings form the basis of the above mentioned framework development activity, which will be discussed in the next chapter.

CHAPTER 5: DEVELOPMENT & DISCUSSION OF CONCEPTUAL FRAMEWORK OF SERVICE-TO-DESIGN FEEDBACK PROCESS

This chapter aims to coalesce the findings from the extant literature and empirical work to propose a framework to guide the management of the field failure feedback process from service-to-design for the purposes of product improvement.

5.1 Deriving a conceptual framework for service-to-design feedback process

The proposed conceptual framework was derived from coalescing key findings from the extent literature and empirical investigation. The framework seeks to improve understanding about the effective management and organisation of the feedback process from service-to-design for the purpose of product improvement. As the research adopted an inductive approach, identifying patterns and themes from the raw data is crucial and this was achieved using Braun and Clark (2006) thematic analysis as illustrated in table 5-1.

Table 5-1: thematic analysis adapted from Clark (2006)

Phase	Description of the process
1. Familiarise myself with the data	Transcribe data, read and re-read data, noting down initial ideas
2. Generate initial codes	Code interesting features of the data in a systematic fashion across the entire data set, collate data relevant to each code.
3. Search for themes	Collate codes into potential themes, gathering all data relevant to each potential theme
4. Review themes	Check if the theme works in relation to the coded extracts (Phase 1) and the entire data set (phase 2), generating a thematic map of the analysis
5. Define and name theme	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme
6. Produce report	The final opportunity for analysis. Selection of vivid compelling extract examples, final analysis of selected extracts, relating back the analysis to the research question and literature, producing a report of the analysis.

The data collected from the case study were clustered into six themes as discussed in chapter 4. The researcher was able to identify key issues within each theme that makes the management of the service-to-design field feedback challenging. These keys issues relates to how the field feedback is structured, the need for service-to-design feedback process, the current process operation, barriers to the process, how field data is captured, analysed and used in making product design improvement. Findings suggest that though the procedure for conducting the feedback process is sequential, this process procedure is not formalised. Another issue is the quality of the information recorded from the field, which are often inaccurate, missing vital information, irrelevant for you. In addition to these issues barriers to the existing process includes lack of direct communication between service and design functions, lack of feedback process management, established roles and responsibilities, lack of efficient feedback facilitation tools and techniques, inappropriate classification of failure data which affects the level and quality of field information that is recorded. Existing literature on the field feedback process has examined it as a fragmented process; however findings from this research suggested that it should be considered as a holistic process that cuts across different functions. Table 5-2 below presents the derivation of the antecedents of an effective service-to-design field feedback

process based on some of the key findings from the literature and empirical study.

Table 5-2: illustrates the derivation of the proposed framework.

Literature	Empirical Findings	Antecedents
Lee and Dale (1998) Huang and Gu (2006) Chao and Ishii (2005) Bragge et al., (2005) Van kujuk et al., (2007)	<i>"Field data requirements have to be defined and this information has to be brought back to the service organisation. the second point is if you speak about the link between service and design, I do not know how it is planned and how dynamic the system will be in the future but it is very important to have a very dynamic link" DE, Rrsp G, Trans 7,p3.</i> <i>There is a problem with selection in the system; the way you select does not give clarity on what you are looking for. E;g when you select the first line it disables some of the options. It need to be redesigned. SQM</i>	Nature of the feedback process
Geudens et al.,(2005) Chao and Ishii (2005) Busby (1997) Petkova et al.,(1999) Busby and Strutt (2001) Menon et al.,(2003) Brombacher et al.,(2005) Dahan and Hauser (2001) Minderhoud (1999) Ouden (2005)	<i>"There are some feedback loops via communication or discussion with service engineers but on a very low level, it's not a process".</i> <i>"There is no link to the history of a failed part on the database which makes analysis time consuming" DE, QE, Rrsp E, G, Trans 5,7,p4,.</i> <i>"I think the database is ok; the problem is the way it is structured, and the way to filter the right data. But there is a need to restructure the way the database presents the information" DE, Rrsp, G, Trans 7, p8.</i> <i>"The level of details of data recorded in the mop-mis, especially in the free text description is a problem" QE, Rrsp E, trans 5, p4.</i> <i>I think it's a good idea if we sit together more and evaluate together the field data, SE,DE,QE</i>	Process operations
Sosa et al.,(2002) Davenport et al.,(2004) Marsh & Stock (2006) Chao & Ishii (2005) Bensaou(1997) Spekman et al., (2004) Petkova et al.,(1999) Whaling and Kemp(2004) Gilgeous (1995) Transfield et al.,(1998)	<i>"I think team experiences should be actualised in a centralised way, that is, in one database and not in a decentralise organisation" DE, Rrsp. G, Trans 7, p9.</i> <i>"The service engineers are involved in the functional design of the early phase of the IP, this could be much more because it is sometimes only one or two service engineers, it is not as much as we would like". QE, Rrsp. E, trans 5, p3.</i> <i>Feedback between service and design can be improved by inviting service engineers to design engineer's weekly meeting.</i> <i>"Design engineers do not know how fault data is analysed. It is difficult to interpret and analyse the raw data presented in the database, especially if you have no understanding of analysis approach. The quality engineers are responsible for the analysis of the fault data" DE Rrsp B, Trans 2,p3</i> <i>"There should be better communication between customer service and design. They should have more frequent meetings with customer engineers and product improvement team but most people don't have that much time". QE, Rrsp A, Trans 1, p5.</i>	Integrating mechanism
Lee and Dale (1998) McNealy,(1993) Braqanza & Lambert (2000) Syamil et al., (2004) Najmi et al.,(2005) Saccani et al.,(2005)	<i>"Improve the situation especially for new product, to have feedback as soon as possible and as detailed as possible. The question is how to manage it, with what kind of tool, with what level of education and who takes responsible for it?"</i> <i>I do not know exactly who is managing the quality of the feedback process, should it be the service or the quality team?SE, Rrsp L, trans 12.</i>	Governance

Data from interview transcript and notes, company documentation and literature were being examined highlighting any information that the author thought could be relevant in terms of process management, suggestions for the feedback process improvement, ideal feedback structure, limitations etc. As more interview transcript were analysed patterns occurred within the data and it was possible to define codes to which data could be assigned. Important statements were highlighted and assigned a code. Records were kept on an excel spreadsheet and regularly updated with more themes and codes as the analysis progresses. This way, the author was able to visualise and make sense of the data. Key themes were clustered, analysed and interpreted. Based on the literature review, expert's interviews and analysis of the case study, the theoretical framework model was developed. The overall research findings illustrate that for an effective feedback process from service-to-design, you need to consider the following four general themes: its **nature, operations, governance and integrating mechanisms**.

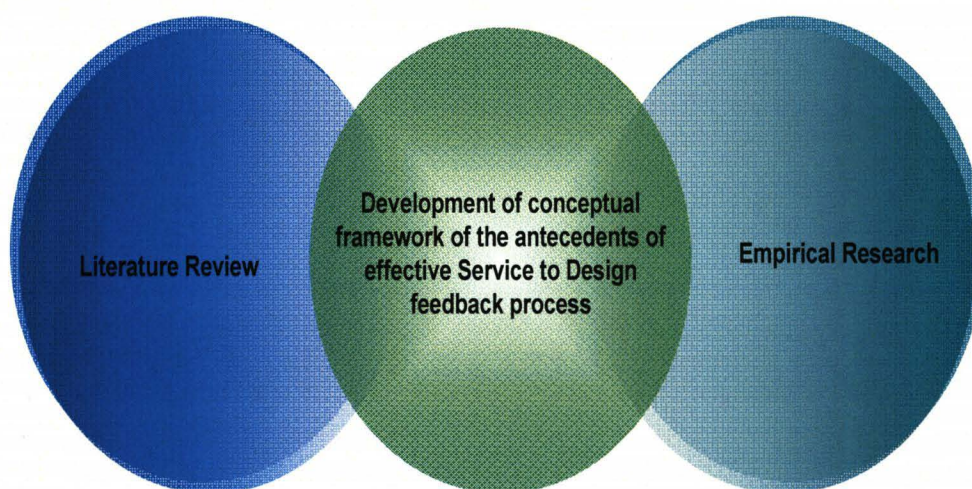


Figure 5-1: Illustrating the research synthesis

The findings show that an effective feedback process should be established by firstly understanding its nature and how it might be characterised. The next step is to define the process of operations which describe the various stages and activities involved in the feedback process. Once this has been established mechanisms to facilitate the synchronisation of its operations need to be considered. To sustain the longer term effectiveness of the feedback process, there is need for a governance structure to enable transparency, dissemination, accountability and evaluation of the performance to steer future process improvements.

5.2 Identifying the key antecedents of an effective service-to-design feedback process

This section is divided into four parts which discusses each of the antecedents as pre-conditions of an effective feedback process in an ideal sense, namely its:

- ***Nature and characteristics***

- **Operations**
- **Integrating mechanisms**
- **Governance**

Each of the above items are discussed, highlighting the empirically derived findings for potential process improvements. In addition, relevant literature is used to support discussion and to further elaborate on important issues. To summarise each section a list of principles and guidelines is presented. Figure 5-2 below presents the proposed conceptual feedback process framework and figure 5-3 presents the discussion map for this chapter.

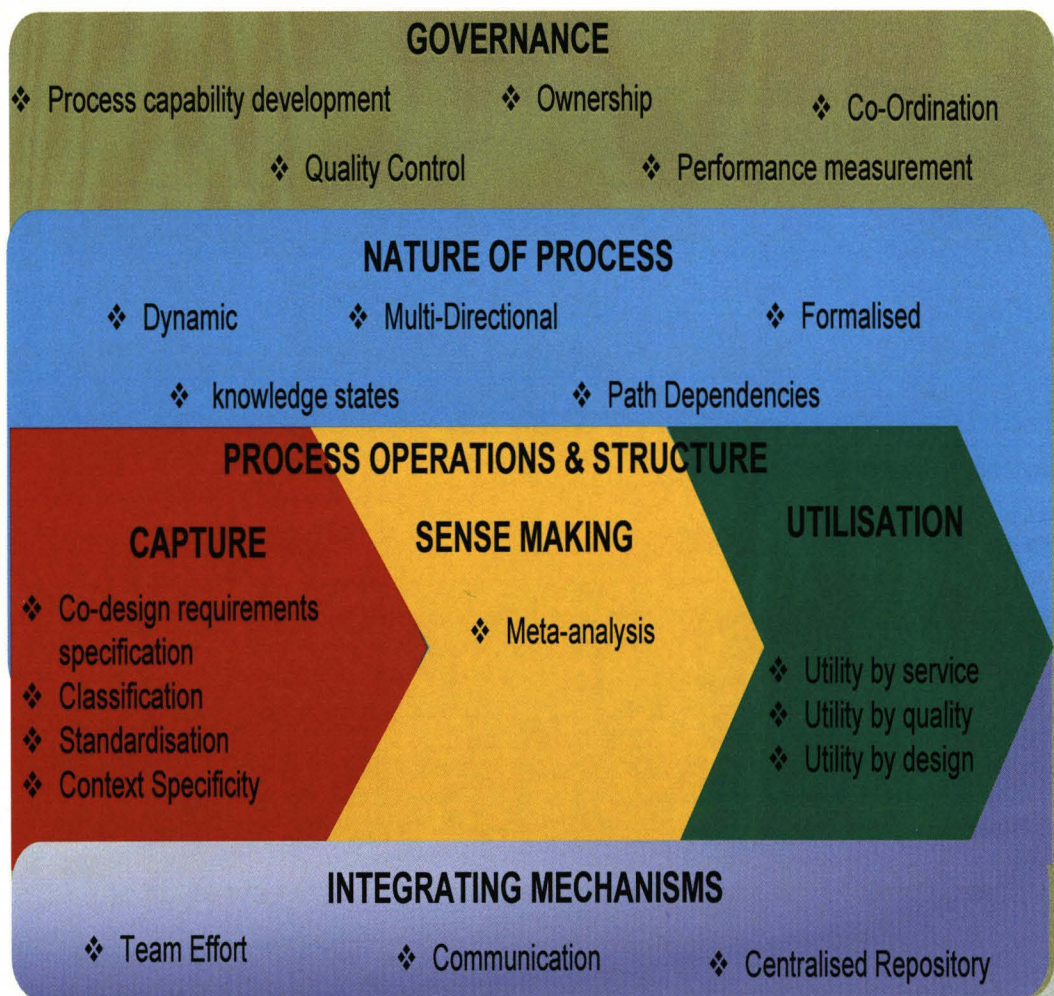


Figure 5-2: Conceptual framework of effective feedback process from service-to-design

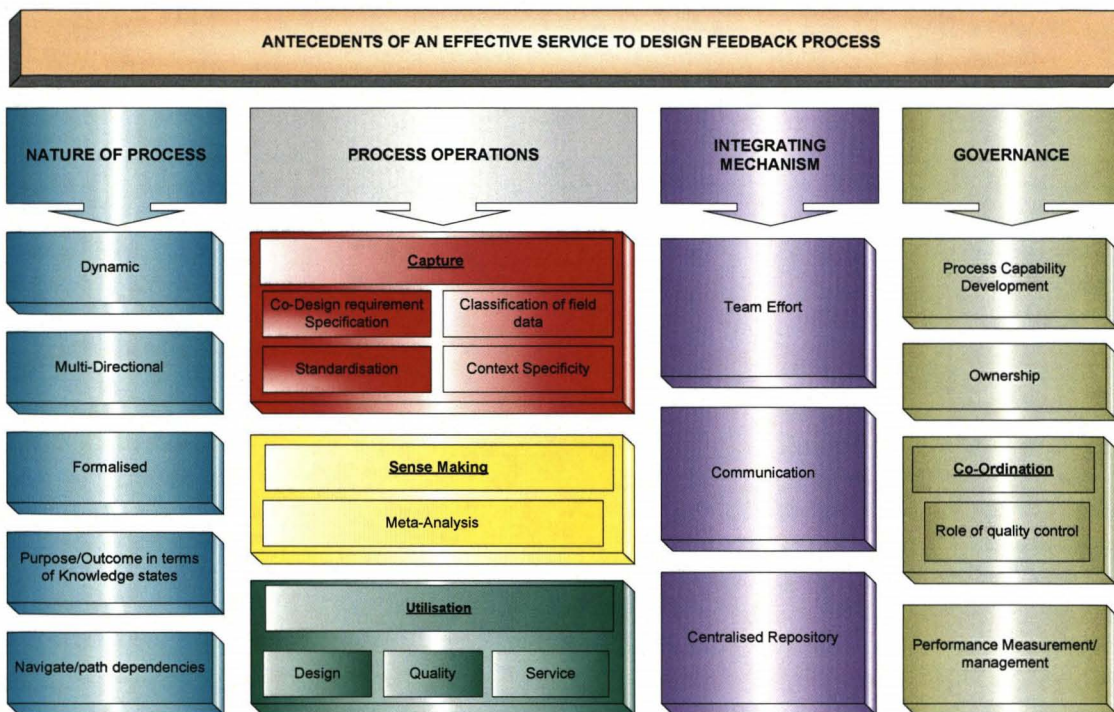


Figure 5-3: Discussion map

5.3 Nature of process

This section discusses the nature of an ideal service-to-design feedback process. Figure 5.4 illustrates a map that highlights key discussion points in subsequent sections.

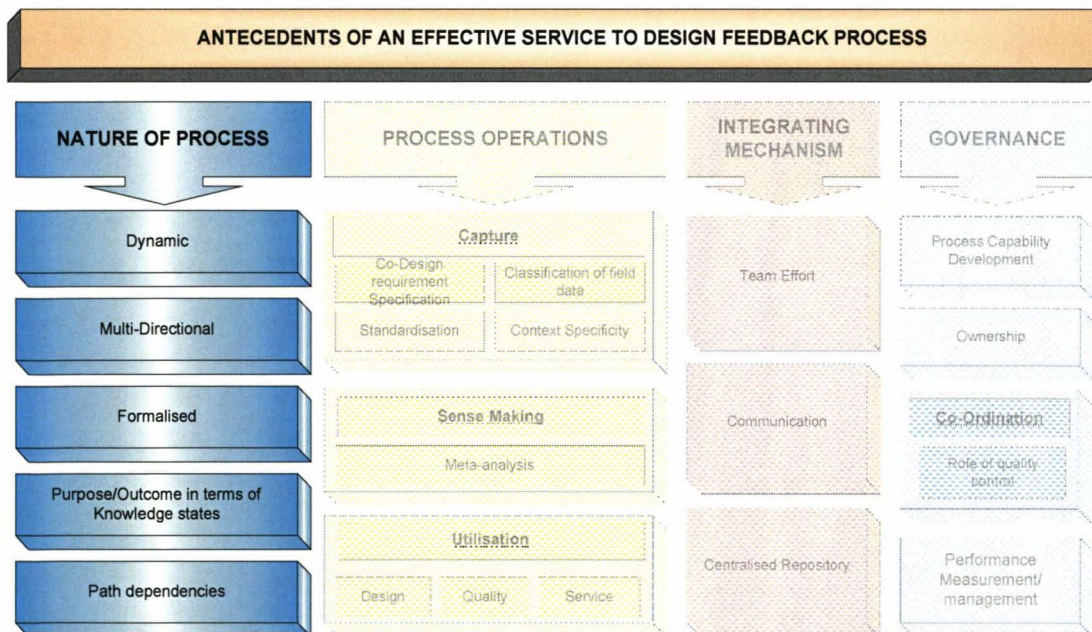


Figure 5-4: Discussion map highlighting "Nature" contents

The feedback process is a learning process. It enables product development teams to learn from existing product failures in the field, establish corrective and preventative actions for improvement whilst maintaining competitiveness through improved product quality and reliability. An effective feedback process offers valuable insights into product performance in the field. Inasmuch they can identify the root cause of the field failure, thereby providing a driver for change. Improved process management demands a better understanding of the nature of the feedback process, if benefits are to be realised. In characterising the nature of the service-to-design feedback process based on the findings from both the literature and empirical study, it proffers to be dynamic, multi-directional and formal.

5.3.1 Dynamic

The field failure feedback as a dynamic process should be a continuous activity that requires regular updates of field failures to enable an organisation to respond quickly to customer complaints and changes in its competitive environment, thus developing solutions that improve product reliability and eliminates future problems. This, in turn, would help satisfy its customers' needs and maintain competitive advantage. According to Eisenhardt (2002) an organisation must be capable of responding quickly to problems in the field, as well as managing unforeseeable environmental demands. Therefore, field feedback from service-to-design should be a dynamic process that constantly captures, updates and incorporates the information on product failures from the field into the design function. Whereupon designers are able to assess current product performance in the field, learn from their mistakes and make necessary design changes to eliminate failures, enhance product quality and reliability, and improve overall product performance and value. According to Bohn (1994) in a dynamic environment, knowledge about the process of product development is incomplete in the beginning and develops gradually overtime through various modes of learning. In other words, the feedback is an iterative process; therefore information that is fed from service-to-design should change over time to proactively meet changes to the requirements of the development team. The dynamism of the field feedback process also means that it should be capable of providing information on all dimensions of the product performance in the field. Examples of such dimensions may include measuring the accuracy of information recorded by service engineers and monitoring the amount of time service engineers spend resolving a problem.

5.3.2 Multi-directional

The feedback process involves the collaboration of multidisciplinary teams; therefore, the flow of information within its operations must be multi-directional. The multi-directional approach entails the feedback and feed forward of product failure data from service-to-design and vice versa. However, it is important that its chain of command is as short as possible. This is because information received and passed through many people is vulnerable to distortion. The process must be understood and conducted without unnecessary complications that can cause delay to the flow of information as well as the availability of field failure data when required in making design changes. It has to be simple so that as few steps as possible should be required for conducting the process.

As it is important for service engineers to feed back field failure data to design engineers to enable them to make design changes and improve the performance of both existing and new product. It is also beneficial for designers to feed forward information on new design changes, as well as the solutions developed for component failures, to service engineers. As a result, their knowledge of the solutions to product failures can be deployed when dealing with subsequent similar failures in the field. According to one of the service engineers:

"We often do not get feedback on the outcome [of the investigation on] of the field failure we provide. I would like to know what happened to the information I recorded"
Service Engineer, Respondent O, Transcript 15, p2.

According to a quality engineer:

Although we often don't provide feedback to the service engineers, I strongly support that the service engineers need to be educated on what the field data is used for"
Quality Engineer, Respondent K, Transcript 11, P4

Existing literature on field feedback process and new product development processes have emphasised the importance of cross functional communication and argue that the transfer and flow of information between cross functional teams should be bidirectional i.e. from service-to-design and from design to service (Petkova and Sander, 2003, Lapierre and Henault, 1996; Pinto and Pinto, 1990). The feedback and feed forward approach seeks to close the gap in communication and provide awareness of problem issues relating to products in the field. From a motivational perspective, the feed forward of solutions or changes made to a product design may convince service engineers to feel that their work is valued and as a result encourage them to capture more accurate and detailed data on product failures in the field. Clearly, the multidirectional approach of the feedback process allows design engineers to learn from the field and use the information for making design improvements, whilst service engineers learn from solutions provided by designer engineers to enable them to diagnose and resolve existing or potential field problems in the future for next generation products. The multidirectional approach to the feedback process should close the loop in communication between design and service through the dissemination of information. The failure information and the subsequent information on the problem resolution that is communicated must be meaningful to both the giver and the receiver of the information. In addition to this, it must also be readily available and easily accessible when required.

5.3.3 Formalised and standardised

One of the major challenges with the existing field feedback process was a lack of procedure and formalisation. Formalising the service-to-design field feedback process aids dissemination of product failure data and would enable a better understanding of what the process entails. It would improve the awareness of the different process stakeholders on what is expected of them at the different stages of the field feedback process. Whilst the dynamic nature of the field feedback process exacerbates this issue, a level of structure would help avoid inconsistencies in duplication of effort and resulting unintended consequences.

Standardisation is defined by Jang and Lee (1998) as "the extent to which work rules, policies and operating procedures are formalised and followed". By standardising the field feedback process, the activities involved in the process

become a routine with clearly defined work breakdown structures. Formalising the service-to-design field feedback process would ensure consistency, whereby the process can be repeated with minimal disparity. According to a design engineer:

"[The feedback process] needs to be standardised to enable us to filter field data in a better way [so that relevant information is generated when searching for field failure data] Design Engineer, Respondent G, Transcript 7, p9".

The feedback process should be structured such that service engineers are able to capture relevant field data, quality engineers can prioritise data in order to assign actions for improvement and designers are able to utilise the result of the corrective actions assigned in decision making and implementation in new product design.

Current field feedback process is ad hoc, in line with Kumar and Harms (2004) argument such information produced from business processes run on an informal basis cannot be used properly in planning and decision functions. Therefore a formalised field feedback process is needed and should explicitly describe a step-by-step guide for conducting feedback from service-to-design on product failures in the field and disseminating the subsequent results of failure analysis. However the activities within the feedback process should be studied for absolute understanding before any changes are made, so that the necessary changes that would add value to the process performance are made. A way of achieving this understanding is through the use of process mapping techniques, which would enable stakeholders of the process to attain consensus through their ownership and participation in developing the process map. Establishing a more structured approach for the field feedback process would improve the timeliness, accuracy, effectiveness for product improvement and reduce the inconsistency in the process. All this might be achieved by standardising the process using process maps and flow diagrams to demonstrate the movement of information; descriptions of key responsibilities of the functional teams, measurements for assessing the process performance, the methods, tools and techniques used for the execution of the process and its linkages to other processes should be clearly presented in the feedback process. By standardising the feedback process the following benefits can be achieved as stated by Ugan (2006):

- Improved operations and increase opportunities
- Consistency resulting in process efficiency
- Easier process control
- Minimise uncertainty and variability in the process
- Improve understanding of the process

Despite the obvious benefits derived from standardising and formalising the field feedback process one of the biggest challenges of taking such action centres on eliciting the tacit knowledge of process users. Tacit knowledge elicitation has been discussed by various authors and it is often said that people often know more than they are able to describe. Polanyi (1966) asserted that personnel involved in a process often develop their own way of carrying out the process and when asked to describe the process often find it difficult to describe it easily.

The existing feedback process in the sponsoring case company is presently largely based on user's tacit know-how and therefore needs to be documented and standardised as procedural knowledge of the feedback process. Developing a standardised feedback process procedure requires team effort involving a range of stakeholders and experts from the service, quality, design and product development functions. In doing so, this will allow the process to be better understood by users and help in reducing the inefficiencies involved through re-inventing the wheel of non-value added process.

In order for the process to be carried out effectively, some degree of structural differentiation authority and organisation might also be required. Structure signifies who is responsible and accountable for conducting the activities in a process and specifies how individuals are grouped within boundaries of control Buckley and Carter, (2002). A formalised structure as described by Amaravadi and Lee (2005) involves the sequencing of activities, articulating their inputs, outputs, and constraints and the manner in which it might be changed for optimisation purposes.

5.3.4 Purpose/outcomes in terms of knowledge states

According to Iansiti and MacCormack (1997) as cited in Sacconi *et al.*, (2006) organisations are moving from a "product centric" form to a "knowledge centric" state. That is organisations are experiencing a shift from focusing on just product delivery but moving towards providing information or knowledge about their product and how its performance satisfies customer requirements. From a design perspective, an effective feedback process should capture field failure information that includes failure root causes which, when analysed, would provide value through use in making design improvements. The purpose of the feedback from service-to-design is to provide specific information on product failures that indicate changes needed to improve the quality and reliability of the product. The changing states of outcomes in terms of knowledge states can be demonstrated through analysing and making sense out of the failure data captured from the field. The context specific failure information when analysed should be transformed to context free information which can be used for product quality and reliability improvement in similar product development projects.

From a customer point of view an effective feedback process from service-to-design would establish the shift from "product delivery" to "service delivery" that is the need for a product to the need to provide functionality where an efficient service is provided to the customer in order to satisfy their needs. From a quality perspective the shift from the identification of failure changes to when failure data is analysed, co-translated and interpreted, would lead to the understanding of the failure, and as a result, the application of necessary improvement measures to prevent failure from reoccurring. Figure 5-5 below illustrates the different changing states of knowledge that could occur as a result of an improved field feedback process from service-to-design.

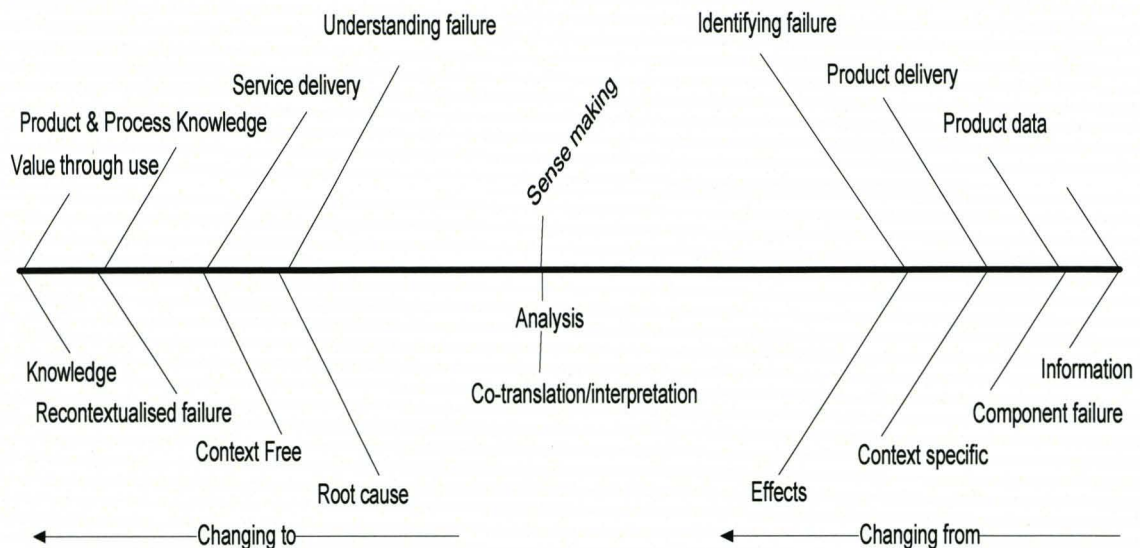


Figure 5-5: Knowledge changing states

5.3.5 Path Dependencies

The feedback process must be sufficiently transparent and show all interdependencies within the process. This subsequently allows for auditability whereby the feedback process and its path dependency on historic data is able to undergo systematic checks to assess the process efficiency and effectiveness.

An issue that emerged from the empirical data is the lack of any link to historic data on similar failed components. Petkova and Sander (2005) argued that it is pragmatic to collect field information that also allows an organisation to check whether it is learning from past experiences. Findings from this research argue that this can only be achieved through good data navigation and path dependency if design engineers have access to historic data of field failures. This could enable useful comparisons to be made about how well they have improved product performance in the field over time by using information about past failures, and to generate best practise remedial action for future product failures.

Davenport and Prusak (1998) suggested that access to historic failure data would enable designers to make well informed decisions when making design changes to improve the quality and reliability in service performance of a product. Schreyögg and Kliesch (2007) asserted that the current position of a firm is shaped by the patterns evolved from the past. In the context of the field data, exploring path dependencies can be useful for service engineers to understand the historical accounts concerning a failed appliance, so that the root cause of the failure can be easily identified and suitable corrective actions can be taken to repair the failure. This also saves time spent on diagnosing and trying to identifying the root cause of the failure. According to one quality engineer:

"A new project has to think about all the possible failures which [could occur in a project] in order not to make the same failures again, [therefore] having a link to the historic failure database [is important]" Quality Engineer, Respondent A, Transcript 1, p6".

For designers this historical account could help them make decisions about which components to include or remove from future new product development projects. An example of information navigation and path dependency might be to establish a link between the historic FMEA database and existing field failure

database. This link would be useful when calculating the possibility of occurrence of failure modes; by including an icon within the FMEA field that links to the field database, data on the failure mode can be extracted to enable an informed decision to be made based on current information from the field. Linking field database to the FMEA process would enable the FMEA team identify existing potential failure modes for a specific components. This will assure relevant failure modes are identified quickly and also reduce the time taken to perform the FMEA process.

5.3.6 Summary of antecedent: Nature of the feedback process

To summarise this section, the principle guidelines for implementation listing the key attributes of the nature of an effective feedback is described in the table below.

Antecedents -Nature of the Feedback process	
Antecedents	Key points
Dynamic	<ul style="list-style-type: none"> Knowledge generated from the service-to-design field feedback process should evolve as a dynamic activity.
Multi-directional	<ul style="list-style-type: none"> The feedback process should engage multi-directional communications and include feed-forward mechanisms.
Formalised and standardised	<ul style="list-style-type: none"> The service-to-design field feedback process should be formalised so that the process can be executed efficiently and managed effectively. In order to formalise the field feedback process the following activities need to be considered: <ul style="list-style-type: none"> Acquire knowledge for each stage of the process, codify and verify from process experts/owners before implementing. Combine the knowledge of the functional teams to develop a process map and provide a description of the process which might include its inputs, outputs, tasks and process owners.
Purpose/outcomes in terms of knowledge states	<ul style="list-style-type: none"> You are moving from an understanding of what is causing the problems in the field to a knowledge state whereby you have a better understanding of how the failure affects other products and Capture context specific product failure data.
Navigation	<ul style="list-style-type: none"> The information in the process must be traceable and show path dependency. An example of this could be to integrate field data into FMEA and establish a link between FMEA and historic failure data.

5.4 Process operations and structure- stages in the feedback process

This section discusses the core content of the feedback process emphasising the three main stages operations as follows;

- Capture
- Sense making
- Utilisation

Figure 5-6 below presents a discussion map illustrating key discussion points under each operation. The summary of the section is later presented using a table to illustrate guidance points to support potential implementation.

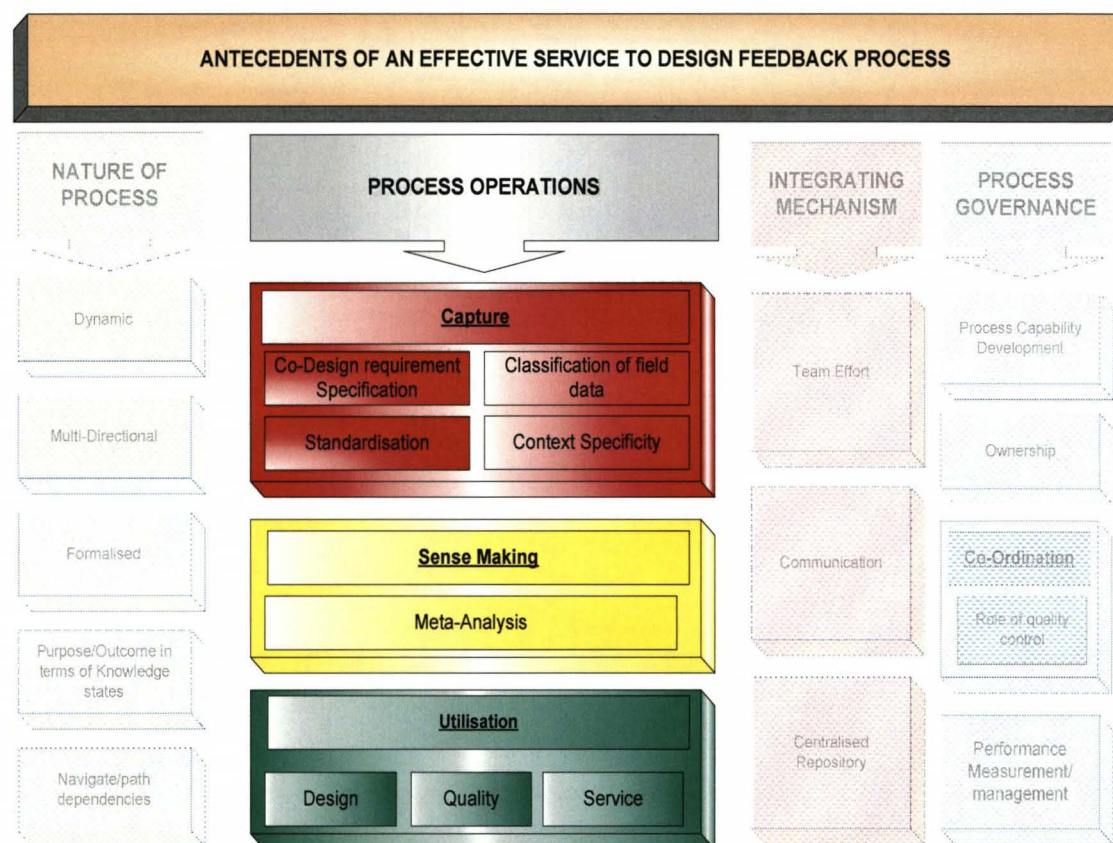


Figure 5-6: Discussion map highlighting “process operations” contents

5.5 Capture

Field data capture process is crucial to the overall service-to-design field feedback process. It should be regarded as a process that indicates opportunities for improving the reliability of a product. The core activity of the field data capture process is the recording of the failure data, which requires describing the failure mode which should include root cause and effect of the failure, as well as any action taken to resolve the failure and general information on the product. Data capture routines should identify field problems requiring immediate attention, corrective actions and provide statistical information illustrating trends of failures. Organisations need to ensure that they can efficiently capture failure data from the field and that such data is readily available to all responsible for product

quality and reliability improvement. The research has shown the limitations of the case study company's data capture process. These areas for improvements are: poor quality of data, inadequate failure data recording system, inadequate failure description, lack of standardised procedure and inadequate classification of failure data. To address these problems the following suggestions are made:

- Co-design specification for field failure worksheet
- Establish classification scheme
- Context Specificity

Each of these areas will be discussed in detail in the subsequent sections.

5.5.1 Co-design specifications for field failure worksheet

The research highlighted that current templates used for recording field failure data restrict service engineers from recording all the necessary field data and from providing an accurate account of their experiences in the field. The deficiencies in the data infrastructure make coherent analysis difficult. Therefore, the approach for improvement should focus on assuring that data is properly collected, stored and presented. According to one of the design engineers;

"The application for recording failure data must be simple enough for service engineers to follow so they can record accurate data" Design Engineer, Respondent H, Transcript 8, p4.

To achieve this, all stakeholders of the feedback process must brainstorm together to co-design a specification format for recording field failure data. Each of the stakeholders have specific requirements for the use of field failure data, all these requirements must be established and used as criteria for designing the data recording templates. The quality and design engineers who input into the service must be represented and their input represented and incorporated into the new worksheet template, so that it is capable of capturing all specific information that is relevant to their responsibilities and contributes to the overall effectiveness of product quality and reliability improvement.

The benefits of co-designing the failure data capture worksheet ensure service engineers record field data that is specific and relevant to both quality and design functional needs. The worksheet would include fields that are relevant for making product reliability improvement. Co-designing the failure data worksheet should also include standardising the terminology used for failure description so a unified understanding is achieved. It should endeavour to remove repetition in options selected by service engineers in describing a failure mode and broaden the options of failure description available to service engineers. Complaints by the service engineers showed that available options for failure description are limited and need to be expanded, so that in situations where more than one failure mode occurs, all data can be recorded. This reduces the existing loss of data as a result of the limited failure description options. As part of the co-design, a standard format for recording textual description of failures must be established in order to encourage uniformity in the style used for presenting further information written in the free text option.

The root cause of a failure was emphasised in the empirical findings and also in literature as being an important criterion for failure analysis and product improvement. The limited time coupled with the complexity of products sometimes makes it impossible for service engineers to identify root cause of a failure despite its importance. To address this issue, the co-designed data capture template should also include a troubleshooting guide. This guide should aim at aiding service engineers in identifying failure root cause. If after using the troubleshooting guide the service engineers are still unable to identify root cause of a failure then a pro-forma could be administered by design engineers to service engineers as a subsequent action to capture more information on a particular failed component. The troubleshooting guidelines should be included as part of the failure recording system. There should also be a self-administered quality check by the service engineer before closing a service job to ensure that an accurate account of the field problem data has been recorded. This should involve a checklist of items that reiterate important data that is required from the field.

The field data capture work sheet should also be designed in such a way as to accommodate the recording of fault codes displayed on the appliance demonstrating its own condition. The current process does not allow for this facility and therefore fault codes are seldom recorded. In the current system, fault codes can only be recorded in the free text option and findings from the empirical study suggested that both quality and design engineers find it difficult to search for data in the free text field. However, designing an extra field in the database for recording fault codes displayed by appliance should link to failure descriptions making it easier to search for potential future solutions. Dhillon (1981) presented a list of guidelines that should be considered when designing the data capture worksheet as follows; simplicity and clarity of the recording forms, clarity in terms and definitions, provide feedback in an effective way to all users, enable flexibility, involve users and capture their requirements, and eliminate the need for memorising codes.

Co-design specification for field failure data feedback when done properly will enhance the product quality, reliability analysis and reporting system and in return allow an organization to generate information from real-time data which can be used in making timely decisions for continuous improvement (Jauw and Vassiliou, 2000).

5.5.2 Classification Scheme

Burrill and Ledolter (1999) defined the classification scheme in two ways; enumerative and faceted. An enumerative method proposes a universal class of objects under consideration and divides them into narrower classes until an appropriate level of detail is established. Alternatively, faceted methods synthesize classes from objects being classified. A faceted method is dynamic in nature because the scheme evolves from data itself whilst the enumerative method is static because it devises classes before examining the specific collection of data to be classified. Faceted method of classification seems appropriate for classifying field failure data, as it is a dynamic activity that evolves over time as a result of changes to product design, increased product complexity and changes to the environmental condition of operation.

The purpose of the field data must be understood before a classification scheme can be developed. The need for developing a classification scheme is to organise field data into a useful format for ease of search, retrieval and storage. The integrity of the data classification scheme must be maintained by ensuring that the structure of the data and relationships among entities are consistent. The categories of failure description should accurately reflect the nature of the problem experienced by the user. The research showed the limitations of the existing classification scheme which lacks clarity, is often vague, repetitive and irrelevant. To improve the quality and usability of the field data, the data must be classified appropriately to allow easy search, manipulation and extraction of relevant field data.

The identified limitations of the existing classification scheme can be addressed by classifying failure data in a format that enhances their usability for example, by reducing the redundant data in the database, simplifying the failure description options and by developing set menu options that are easier to use. An improved data classification should eliminate current confusion faced by service engineers in selecting the most appropriate failure description that represents the problem. The failure data classification should help service engineers in locating problems from general to more specific issues. For example, suppose there is a problem with the boiler system, the failure data classification scheme should be used to describe whether the problem is with the appliance, or if the problem can be narrowed down to the components within the appliance or further narrowed down to the parts.

The classification of failure data should be limited to data that is really needed for subsequent use and analysis, thus providing fewer clusters of irrelevant data. According to Burrill and Ledolter (1999) there is no right or wrong way to classify data. However, the effectiveness of data classification can be proven if it serves the users purpose of use when analysing the data. The classification should be structured to enable quicker data entry, data search and extraction of information and its format should be logical and consistent in order to understand the fundamental message in the data. The field data can be classified in different ways as long as it serves the purpose of analysing the data for product improvement. For example, taking the heating system technology, field failure data can be classified using the following classification scheme:

- Product
- Model
- Serial number
- Part
- Fault code
- Action taken

There is a need to standardise failure description before it can be classified. Standardisation in relation to field data refers to the need to standardise the terminology used in the process, in order to eliminate ambiguity and establish a common understanding by all stakeholders on the data content. According to Juran (1992) vague terminology is unable to provide precise communication.

Hence, there should be a standard format for writing free text in order to reduce variances in the style and content, and eliminate the current difficulty in extracting relevant information from it. Abbreviated words are often used in the free text field. To ensure a common understanding of these abbreviated words, a specified list of abbreviated words with their meaning should be defined and this must be understood by all users of the field failure database. For the free text option to be effective the content should be written in a format that enables ease of clustering and common interpretation which enhances its usefulness. Kumar and Harms (2004) asserted that standardising operations would result in common techniques for similar operations, whilst allowing the flexibility to recognise differences in the process. Whatever classification system is employed for the field data, it is important that it must be understandable and easy to use by the feedback process stakeholders.

5.5.3 Context specificity

Two types of data can be captured and recorded in the failure database namely; static and dynamic data. Static data according to Simon *et al.*, (2001), refers to the specifications of the products, materials, components and suppliers, servicing instructions and end-of-life information. Whilst the dynamic data is collected during the use of a product, for example, pattern of usage, environmental conditions and servicing actions. Some of the existing literature on field failure feedback process has referred to static and dynamic field data as soft and hard failure, and technical and non technical failure (Petkova *et al.*, 2005; Petkova, 2003; Geudens *et al.*, 2005). Findings from the empirical investigation highlighted that data captured from the field is mainly component related which is more of a static type. There is a need to capture more dynamic data that is context specific on product failure. This is essential for understanding root causes of failure. The field data capture should collect data in-situ. This includes data on the operating condition of use or status of the appliance before it failed. Data capture in situ can enhance the process of sharing information by providing rich data that can be re-contextualised to become knowledge, which can be used for decision making during the development process. In addition to the textual description of failure, other methods of data collection can be used such as taking photographic images of failed components to illustrate an appliance condition of use. This could help a design engineer better understand the failure description provided by the service engineer. However, it should be noted that only photographs of unusual component failure or appliance condition should be taken to avoid creating large volumes of photographic images that are redundant. The service engineers PDA system should be enhanced so that it is capable of capturing context specific information through photographic images and sound recording. Useful non product data should be recorded, for example, customers' description of the failure or symptoms of failure which occurred. Failures that occur in the field are always situation bound, therefore field failure data should also record information on the context in which the product did not function as required and also did not satisfy its user.

5.6 Sense Making

Sense making is an important operation in an effective service-to-design feedback framework. Klein *et al.*, (2006b) argues that sense making is a process that recognises the inadequacies associated with current understanding of events, often generated by poor quality of failure data. The sense making

operation can be considered in distinct parts as illustrated in figure 5-1 below, each of which will be discussed in the following sections.

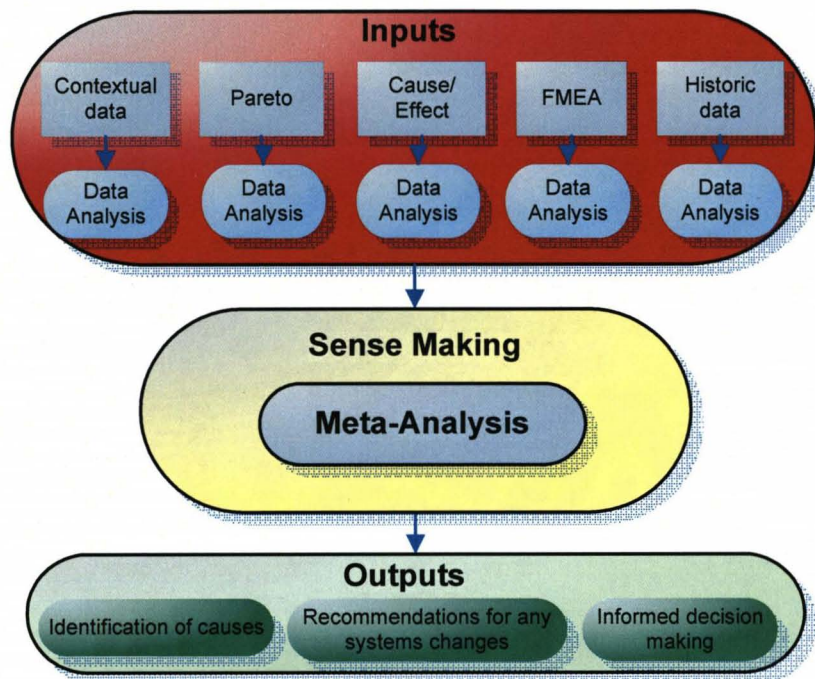


Figure 5-7: Stages of the sense making operation

5.6.1 Meta-Analysis

Different analysis methods of failure data are pursued and provide an input into the sense making process. Current practises on FMEA, Pareto and cause/effect data analysis provide a partial view, and analysis on contextual and historic data should be performed. The failure data used for analysis is incomplete and the feedback process stakeholders are not making a holistic sense of the failure data that is captured. The failure modes are prioritised using the Pareto analysis; for quality personnel to identify frequency or volumes of field failures and agree on the problem to focus on. According to one respondent;

"Pareto chart is used to look at the highest volume of part/component failures which is grouped into several clusters. The longer a part is used in product series the lower the failure rate. However, just because a part was exchanged a lot of times does not mean there are a large number of problems (Design Engineer, Respondent D, Transcript 4, p5).

In problematic situations where further investigation is required the FMEA technique is conducted to analyse potential reliability problems. However, it does not capture historic information on component failure modes in order to achieve the greatest improvements.

Currently there is no link to the history of a failed part on the database. Each rejected part or replacement part should have its own history and there should be a

link in the database to this information (Design Engineer, Respondent G, Transcript 7, p8).

The principle of Pareto analysis (also known as the 80%-20% rules) is that by doing 20% of the work you can generate 80% of the benefit of doing the whole work. The reports produced from the Pareto, cause/effect analysis and FMEA analysis are used by design engineers in generating solutions to product field failures. As stated by one respondent:

"A challenge of field failure data analysis is the lack of access to information about part failure history. There is no link to historic data on failed part, which could help in understanding [a field problem]"

To have a holistic view of the various data analysed, stakeholders need to capture contextual and historic data as part of their analysis and improve the overall quality of data recorded. The subsequent outcomes from each of the different data analysis should form inputs to a broader meta-analysis.

Before a meta-analysis can be conducted, relevant failure data needs to be collected and analysed using input data analysis as illustrated in figure 5-1. Meta-analysis begins by synthesising the different levels of analysis. The subsequent outcomes from the meta-analysis would enrich the sense making process to move towards identifying causes of failure in a holistic manner.

The purpose of sense making is to establish an understanding of root causes of failure. This is done through meta-analysis and by co-interpretation of the information presented to establish an integrated multidisciplinary understanding of the field problems and failure. Schon (1983) states that sense making ensures that problematic situations are identified and framed, boundaries for interventions are defined and a logical approach is formed to develop actions to resolve problems. In doing so, this makes design engineers aware of the consequences of their design decisions and its effects on product performance and ultimately customer satisfaction.

Meta analysis requires interdisciplinary contribution from the service, quality and design personnel based on their diverse skills and experiences of similar past product failures, how they might evolve over time, its effects, causes and what potential action should be taken. This would enable them to contribute to the generation of solutions out of which the most effective one can be chosen to establish preventive actions for eliminating the failures or reducing the possibility of reoccurrence. They are bringing experiential learning from practise into the co-interpretation of failure data and this influences their understanding of the problems and knowledge outcomes from the sense making operation. The contribution of each functional personnel shifts the awareness of field problem from a uni-disciplinary perspective to a shared and multi-disciplinary understanding. Saban *et al.*, (2000) states that establishing a shared interpretation requires a consensus on the meaning and implications of the new knowledge generated.

The knowledge outcomes from a holistic sense making activity would include root cause of failure modes, agreed recommendations for any system changes and also inform design engineers decision making process during product design.

5.7 Utilisation

The effective utilisation of product field failure information is dependent on appropriate capture and sense making process to generate new knowledge for making decisions during product development. Ottum and Moore (1997) asserted that capturing the field information is simply not enough, and in addition to this, there is a need to share the information so that it can be discussed from a different perspective and used in different functional areas. The utilisation of the product field failure information is determined by characteristics such as the timeliness, accuracy, relevance and level of details the information possesses. If the feedback information is lacking these characteristics its usefulness comes into question.

One of the challenges of using a feedback process is the need to manage the flow of the information from service-to-design. The feedback process has distinct advantages for product improvement providing dissemination of data for use in the product development process. Wheelwright and Clark (1992) and Meyer (1993) asserted that the rapid dissemination and utilisation of information is determined in part by the structure of the organisation.

The use of field failure data collected varies in the quality, service and design functions. Despite these differences, the key stakeholders of the feedback process require timely and accurate product failure information to assist them in the analysis of product performance and aid decision making. The frequency and regularity of the feedback information flow has the potential to lead to more reliable information flow which can be used to make real time product improvement and enhance interdisciplinary collaboration. Effective utilisation of feedback information requires the information to be kept up-to-date and user-friendly. Each of the process stakeholders requires a certain level of accuracy, completeness and consistency to make good use of the field data feedback process. Therefore, the management of the process must ensure stakeholders' expectations are met, so they don't lose confidence in the process.

According to the findings from the empirical study the large volume of data stored in the field failure data repository (MopMis) makes it difficult for users to manipulate the database to extract relevant information. Suggestions for improving the field data capture operations recommended a redesign of the repository to have interfaces that are specific to functional users of the database. By doing so, only information that is relevant to them will be presented.

Useable in these terms means, it must not only capture component related field information but contextual information such as operational and environment conditions must also be recorded. A number of literature authors (Brombacher *et al.*, 2005; Busby, 1998; Petkova *et al.*, 2005; Molenaar *et al.*, 2002) argue that failure is not always component related; instead, product failure may occur because of its integration with other systems in its operational environment.

The feedback of field failure data as well as outcomes derived from its analysis is an important driver for organisational learning. If properly harnessed it could be reused to improve on the product development processes. Learning derived from the feedback process would enable service and quality functions to monitor and detect product reliability changes whilst the designers are able to determine whether the reliability of the product design changes has significantly improved

over time. The utilisation of the product field failure feedback process varies between service, design and quality functions, however the common consensus is that outcome from the failure analysis is used with all three functions towards the objective of improving the product quality and reliability.

Service operations are key to the utilisation of field data by other product development functions in particular design and quality. After product launch it is the responsibility of the service department to monitor and record data on product performance in the field. According to Honari *et al.*, (2007) early monitoring of field failures ensures that adverse changes in the production process are identified quickly to avoid dealing with more severe reliability problems. Service as a function is the main generator of product field failure data. Their main use of the feedback information is for learning and failure diagnosis purpose. Service should make use of the outcomes from product failure analysis in developing service innovation to differentiate their services offering from their competitors. Service innovation in this thesis means providing a new concept of service in addition to the physical product. For example, by providing added value to customers' experience of using a product. This could be in form of extended reliability guarantee whereby customers are offered servicing, repairing, maintenance or replacement of product if it is still within the warranty period. They should provide and maintain the service functions of a product and offer activities and schemes that enable long-term durable products (Mont, 2002). Outcomes of the failure analysis can be used by the service function to provide consultancy functions whereby customers are trained on how to use the product more efficiently. It can also be used to improve the capability of service engineers through training.

The feedback on field failure data is used by a quality team to detect root causes of failure through analysis of the field data using the FMEA technique. Field data is analysed to generate a multiplicity of information to aid the forecasting of product reliability and creating quality targets for improved new products. To utilise field failure in reliability prognosis the feedback from the field must be timely and readily available. The issue here is with the quality of the information. If the quality of the field information is poor, the outcome of its subsequent use would be inaccurate and would greatly affect the quality of the products. It is therefore, vital for quality personnel to assess the quality and reliability of the data that is disseminated from service before use in product improvement operations. The product failure feedback information should be used by the quality personnel in optimising the product improvements process by using the information during FMEA sessions to anticipate potential failure modes that could occur in current and new product development processes. Berden *et al.*, (2000) stated that anticipation is only possible if enough knowledge of the subsequent processes is available.

The utilisation of product failure information is mostly required during design operations by converting feedback on a product. Designers make use of field failure feedback because they provide failure information on the actual usage of a product operating under real-time environmental conditions. Coit and Dey (1999) urge that rigorous laboratory testing cannot consider or predict precisely all the field conditions that could result in component failure. Therefore feedback on field failure is important to designer engineers as it represents actual performance of the products in the field. This information could be used in building redundancy into the product to reduce the possibility of failure. According

to Petkova and Sander (2005) lack of access to feedback on field information means that a manufacturer might produce products that are only reliable under laboratory conditions and perform terribly during customers' usage. For design engineers the availability of field data is important for making improvements to new product design to enhance its reliability and ease of service support. At this stage the field feedback process should be viewed as an opportunity for improving the existing functionality of a product and building new functionalities and develop product innovation that can be offered to their customers in new product generations. This requires an efficient feedback and feed forward process so that relevant good quality and accurate failure information can be embedded early in the product design process. This also provides an opportunity for designers to assess if they are learning as well as improving on their past failures.

Antecedent- The stages of the feedback process	
Antecedents	Key points
Field data "capture"	<ul style="list-style-type: none"> • Co-design a requirement specification template for field failure data capture to ensure all process stakeholders product improvement needs are met by: <ul style="list-style-type: none"> ○ Establishing goals for the field data collection. ○ Identifying the various types of data required by the functional teams. ○ Establish standardised terminology of failure description and rules for free text option. • The co-designed data capture template must be capable of the following; <ul style="list-style-type: none"> ○ Sufficiently flexible to accommodate potential and future requirements. ○ Create integrity rules that validate the quality of data captured by service engineers. ○ Provide service engineers with tools or knowledge to determine root causes of failure.
"Sense making"	<ul style="list-style-type: none"> • The purpose of the sense making process is to analysis failure data from a holistic view. Therefore a meta-data analysis should be conducted to inherent information contained in the various field data analysis outcomes. During this process it is important for all the process stakeholders to co-translate and interpret field data.
"Utility"	<ul style="list-style-type: none"> • Outcomes from the field data analysis should be used in design functions for improving product quality and reliability. It should be used by the quality to make future product reliability prognosis and used during FMEA to identify failure modes, causes, effects and corrective actions. It should be used in service to develop service innovation.

5.8 Integrating mechanisms

The core activities of the feedback process operations have been established in the previous section. Effective feedback processes require an integrative mechanism that brings together stakeholders, the field feedback information and process operations. Such mechanisms would establish channels of communication between the process stakeholders in order to keep them informed on the performance of the product in the field and its implications on customer satisfaction. This section describes and discusses the methods that should be used for integrating the feedback process operations to ensure the smooth running of the three key operational stages and their sub activities. Figure 5-9 below presents the discussion map with the key issues to consider for an effective integration.

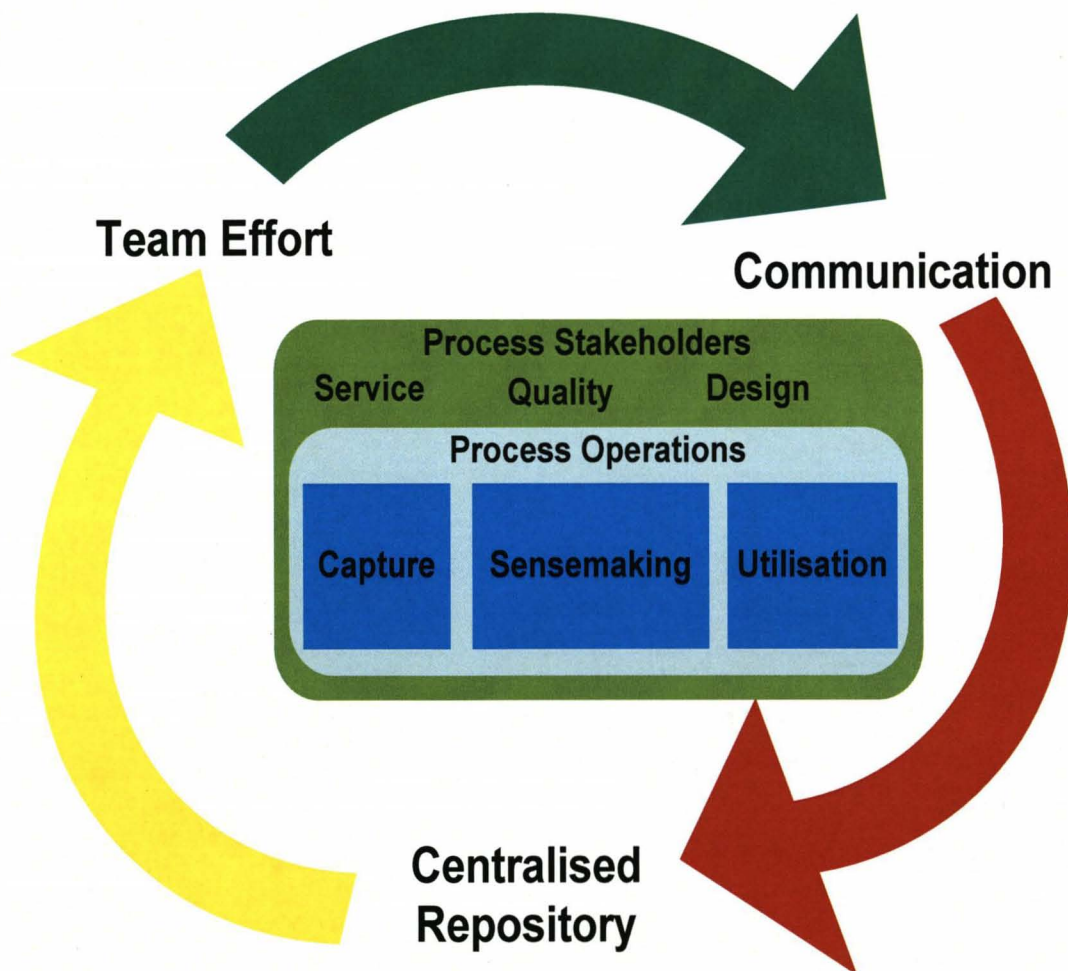


Figure 5-8 Integrating mechanism

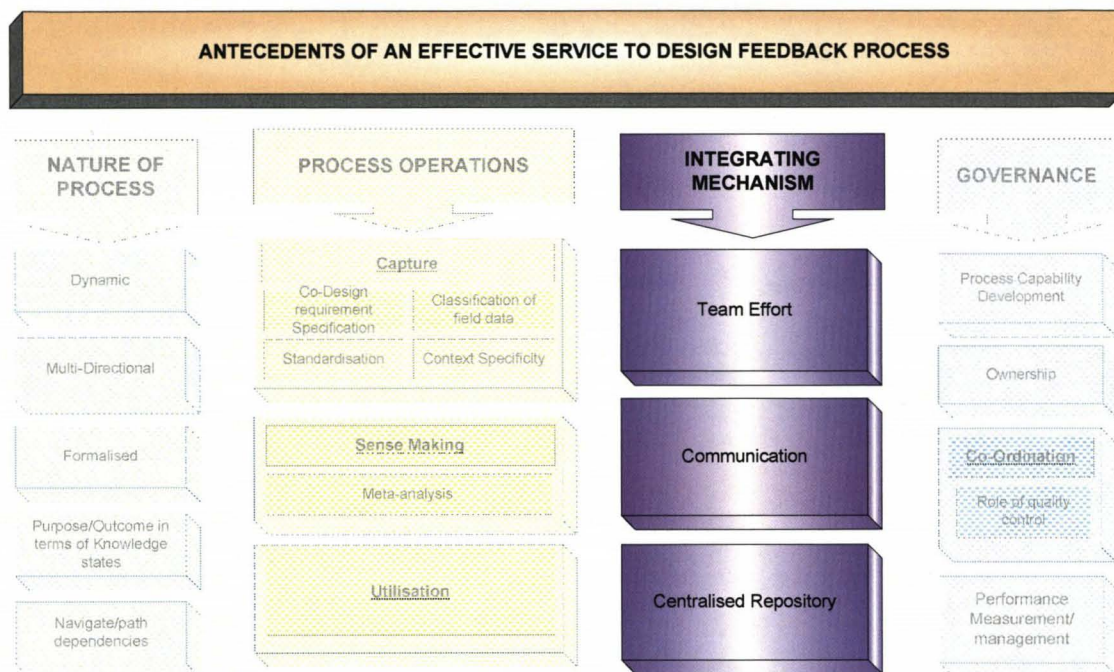


Figure 5-9: Discussion map highlighting “Integrating Mechanism” contents

Lawrence and Lorsch (1986) define integration as “the quality or state of collaboration that exists among departments that are required to achieve unity of effort”. Integration in this thesis refers to the method of collaboration, cooperation and overall communication within the feedback process. Findings from the literature asserted that integrating business operations is attainable through common policies, action plans and shared information used in making decisions, based on common knowledge (Kumar and Harms, 2004, Kesner, 2001, Ravichandran and Rai, 2000). The integrating mechanism is a two dimensional construct which consists of both interaction and collaboration, Kahn (1996). Furthermore this collaboration between cross functional teams has been divided in the literature into two elements; one is information transfer such as field data which is aimed at reducing uncertainty in the product (Lapierre and Henault, 1996) and the other is participation of each function in product development activities to influence changes (Lapierre and Henault, 1996). In the context of this research, an effective integration mechanism is required for the dissemination of field information, the facilitation of effective communication between stakeholders and for encouraging collaboration between functional teams so that they are well informed and kept up-to-date on product failures in the field. Findings from the empirical investigation have established three methods of integrating mechanisms for the effective management of the product field failure feedback process operations, these are team effort, communication and centralised data repository. Each of these facilitating mechanisms will be discussed in the following sections.

5.8.1 Team Effort

Team effort is defined in this thesis as the cooperation between people and the need to make use of various know-how or experience in accomplishing a task more effectively and efficiently. Teare *et al.*, (1997) argued that team working is a means by which business processes can be integrated. Thus, collaboration

between teams would provide a means to access and share a multiplicity of knowledge essential for understanding how they could work together (McIvor *et al.*, 2003; Zineldin and Bredenlow, 2003). Team effort can be improved through interdisciplinary immersion and learning from each other's role. According to Ottum and Moore (1997) a reason for lack of integration between functional units is the lack of understanding of each other's job. With a greater understanding of each other's job, designers would make better use of field information whilst service would capture more detailed and relevant data that is useful for designers. The process of interdisciplinary immersion involves the exchange of personnel from one functional department to experience the activities performed in a different functional department. For example, service engineers could take it in turn to experience a day with a designer, to understand the activities involved in designing a product, understand the type of information required by designer, how the field information is utilised during the design process, and understand the problem designers face with regards to the information captured from the field. Conversely, designers should also experience a day working with a service engineer by attending field call outs to understand the processes involved in service support, understand how service records field failure data, the effectiveness of the service data recording system, difficulties encountered by service engineers in the field with regards to the product design, understand the service engineers requirements and the current limitation of the support process.

The interdisciplinary immersion in each other's work is an effective way of learning and improving on current functional practises based on the experiences gained from this approach. Efficient team effort within the feedback process would provide richer information that represent diverse viewpoints. According to (Schilling and Hill, 1998) team efforts provide a broader knowledge base and increases the "cross fertilisation of ideas". When utilised appropriately it would serve to improve product quality and reliability as well as prevent same failure from re-occurring. It is important that both service and design engineers meet regularly to discuss the latest defects in products, problems experienced in the field and problem experienced in using failure information from the field. These meetings can be held as often as required, for example, weekly or monthly. However, it is important that they are held, with set actions to be investigated. If possible solutions to these must be developed and discussed in the subsequent meeting. However it is important for the teams to have a clear understanding of their responsibilities towards the feedback process and how to contribute to its effectiveness. On the other hand the organisation must provide resources that fulfil the need of the team in making effective contribution to the feedback process.

5.8.2 Communication

Emerging problems from the empirical study highlighted communication as one of the biggest challenges of field failure feedback process from service-to-design. An example of these challenges is the vagueness and lack of clarity in the field data recorded by service engineers. Communication is the process by which individuals share meaning (Holm, 2006), and timely information (Anderson and Gerbing, 1985) in order to reach a mutual understanding (Rogers, 2003). Within an organisational setting communication can be classified into formal and informal methods. Formal communication uses channels which flow either within an established chain of command, defined previously by the organisation, whilst informal communication are unofficial exchanges of information (Daft, 2003).

Effective communication within the product development team, in particular between service and design, should be documented and disseminated to all appropriate functional units, emphasising collective and individual responsibilities and accountabilities. The medium deployed to facilitate communication between the functional teams is an important factor in assuring the effectiveness and efficiency of feedback process. As identified in the literature there are two types of communication methods which can be used to enhance the effectiveness of the product field failure feedback process; traditional and advanced communication methods (Carr *et al.*, 2007). Traditional communication methods involve the use of telephone, fax, written memo and face-to-face contact (Leek *et al.*, 2003; Carr *et al.*, 2007). Whilst advanced communication methods involve computer to computer links, electronic data interchange (EDI), etc. Findings from the empirical study and existing literature on product quality and reliability improvement using field failure data indicated that communication among functional units facilitates information sharing; therefore it is an important antecedent of an effective feedback process from service-to-design.

Communication and team effort are indispensable tools which can be used to respond immediately to issues arising from the field. The lack of communication is a barrier that prevents interactions in product development and the more efficient communication is, the more co-ordination there will be and the less autonomy each functional unit will have. Efficient communications structure consequently facilitates interdependence. That is, the ability to transfer field failure information as quickly and effectively from service-to-design. However, the effectiveness of the information shared depends on the sufficiency of its details, its frequency and timeliness (Leek *et al.*, 2003). The primary motivation behind service feedback about product field failure data to design is to improve both existing and new product generation quality through the use of product in use performance data.

Another important factor in the effective management of the feedback process is the need for an appropriate communication infrastructure to reinforce and support cross functional integration. According to Goh (2002) this can be achieved by developing a horizontal communication flow, which goes beyond using technology.

At present, the nature of the relationship between service and design engineers is a barrier to the effective management of the feedback process. The indirect communication link between both parties needs to be improved by ensuring close relationship through regular meetings, workshops and direct contact. Direct telephone contact between service and designers should be established to encourage quicker information sharing and communication between both parties. By so doing, service engineers, when faced with complex situations in the field, are able to seek support directly from the designers responsible for the product.

The lack of communication between service and design functions can be disadvantageous to the product improvement process. The miscommunication among the cross functional teams can lead to poor integration between product attributes and customer requirements (Schilling and Hill, 1998). There is a need for service to communicate current product performance in the field back to the designers to ensure that necessary changes are made to the product design, in order to eliminate defects which in turn lead to an improved quality. Although

mutual understanding and collaboration are urgently required among the cross functional unit, this rarely happens because they have their own viewpoints.

Nevertheless learning can only occur when knowledge in one part of an organisation is transferred effectively to other parts and used to solve problems or to provide new insights. Knowledge transfer is key dimension of a learning organisation (Goh, 2002). Hoopes, (1999) stated that an organisation which encourages free circulation of information and knowledge within the organisation appears to come up with new products faster and better and uses fewer man-hours in doing so. According to Neito and Perez (2002) and Swift and Hwang (2008) effective organisational learning requires both tacit and explicit knowledge, which is used for increasing competitiveness and effectiveness within an organisation. Information dissemination within the organisation should be driven by the communication processes and information flows which should be integrated in facilities such as information technology systems. The information technology function plays a vital role in the process integration. However it must be seen as an enabler and not the driving force of the process integration (Talwar, 1993).

Using the appropriate communication tools such as intranet, workshops, team meetings, memos, emails, telephone and face-to-face conversation as methods for field information, can expedite the feedback process and maximise its effective management. Sahin and Robinson (2002) asserted that communication methods are enablers to information sharing. The use of communication methods such as email, electronic data exchange broadens the accessibility of information (Bhatt, 2000) and facilitates communication using variety of information networks (Dewett and Jones, 2001). Bhatt (2000) argues that information sharing within an organisation helps stakeholders in identifying critical issues and promotes teamwork (Dewett and Jones, 2001).

Another method of communication is through the facilitation of workshops. A workshop session could also be organised to gather people from design, quality and service departments together to explore specific issues and problems using a hands-on approach and the involvement of all participants in order to learn or acquire new information and brainstorm together to generate new solutions. A workshop provides an interactive opportunity for the participants to discuss and share their different perspectives on the subject of the workshop. According to Gilgeous (1995) it can be used to familiarise groups of people with each other, develop individual skills, enable views and knowledge of others to be shared and questioned and improve understanding on a particular issue. In the context of this research regular workshop sessions should be organised between the design, quality and service units of the case company as means of communicating, sharing and learning from issues raised and discussed during the session. The session should be used as an opportunity to identify ineffectiveness in the current feedback process and develop action plans to improve the process.

The use of web delivery technology such as the intranet can also be used for facilitating communication among the cross functional team involved in the feedback process. The intranet can be used for communicating current issues in the field and on-going actions to resolve these issues. It can also be used to communicate procedures of the feedback process. Skok and Kalmanovitch

(2005) described the intranet as an information sharing tool designed around people who share the same processes.

5.8.3 Centralised data repository

There is a need for a Centralised data repository which consists of a database of field data and Historic FMEA database. This should be used among the functional unit for data sharing and accessing of up-to-date information on product failures in the field, deciding on action taken on each problem and solutions developed to resolve problems. The centralised data repository can be managed through regular update, cleansing and archiving of old data to allow easy access to up-to-date and relevant information. However, it is important to keep the information within the centralised data repository structured in order to avoid neglect from its users. As well as the centralised data repository the feedback process needs to be properly documented to ensure that an accurate record of events is maintained, which can be used as evidence if required.

Antecedent- Integrating Mechanisms	
Key Attributes	Guidelines
Team Effort	<ul style="list-style-type: none"> • Conduct interdisciplinary immersion, so that each functional team can understand and learn from each other's role and improve on current functional practises using their experience.
Communication	<ul style="list-style-type: none"> • Establish appropriate collaboration and communication methods between service, design and quality functions, to improve the efficacy of the feedback process through the following: <ul style="list-style-type: none"> ○ Conduct regular meeting with process stakeholders. ○ Organise workshop session for knowledge sharing, brainstorming, discussion and hands-on practical experience. ○ Direct contact via phone, memo and email ○ Intranet
Centralised Repository	<ul style="list-style-type: none"> • Develop a centralised data repository which must be user-friendly enough to easily extract relevant information out of it. • Team effort, communication technology and centralised repository should compliment each other in order to generate a synergy that would improve the effectiveness of the feedback process to support product improvement.

5.9 Governance

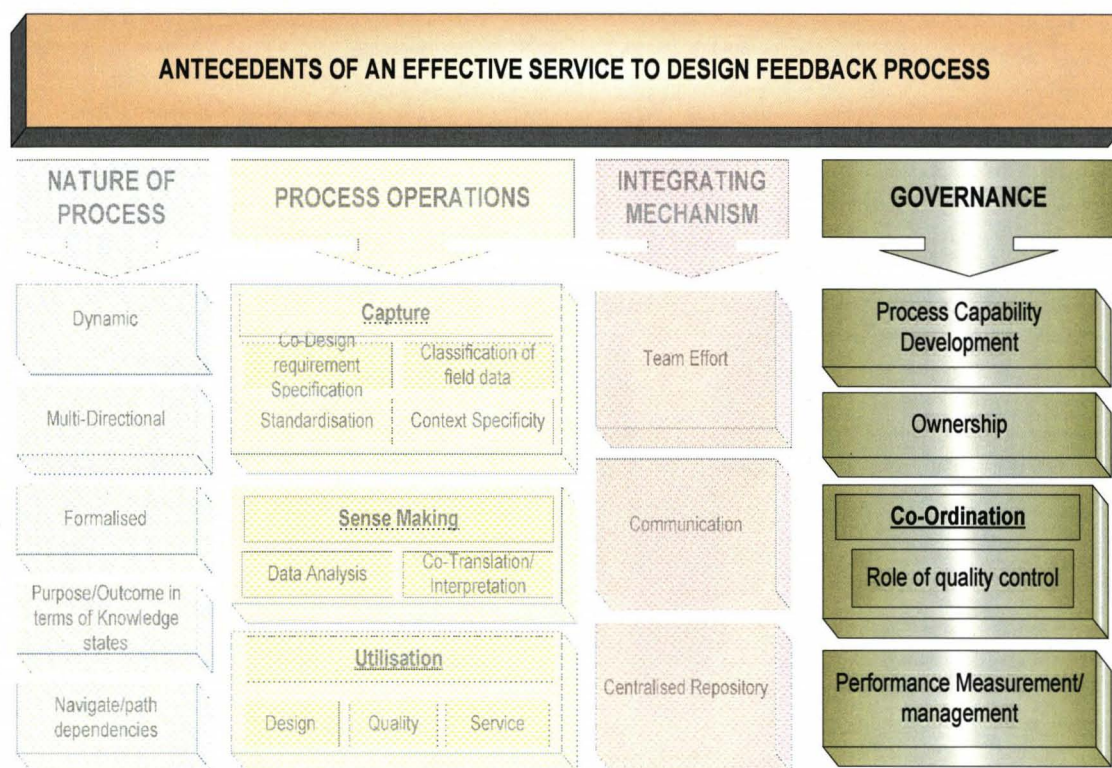


Figure 5-10: Discussion map highlighting "Governance" contents

Governance is defined as set of rules that dictate or govern how an organisation must conduct a specific business function. Thus process governance involves guidelines and resources that an organisation uses to facilitate collaboration and communication when executing business processes (Richardson, 2006) such as the feedback process from service-to-design. It is concerned with the sharing and performance of responsibilities within the organisation. The importance of process governance in the feedback process is to ensure consistency in the activities conducted, establish effective communication and training among all stakeholders and improve their understanding of the feedback process procedure.

The governing structure needs to ensure that the feedback process is capable of delivering its intended purpose and is not undermined by other operational priorities. Consistency in the feedback process is required in order to understand the process and identify ways of improving it. They need to ensure that the process is implemented and working correctly. A regular review of the process should be conducted. The focus should be on ensuring that the process is meeting the expectations of the users, providing real benefit to all stakeholders and producing data to facilitate improvements. The process should be open to feedback from all parties and suggestions for improvement should be properly considered to show that the opinions of the users are valued and they are encouraged to contribute to its continuous improvement.

The procedures and controls established in process governance should be used to manage and co-ordinate the process information. Since governance in business operation is a process of decision making and the implementation of

these process decisions. It is necessary to have structures in place that aid the decision makers in arriving at and implementing the decisions made during a process. The goal of the feedback process governance should be to create a method for process improvement and dissemination by defining the procedure for the field failure data process that governs the access and use of the feedback process information. The governance structure must define procedure for communication, approval and permissions between the various stakeholders of the feedback process. The governance of the feedback process should address activities such as the process management which includes, monitoring, controlling and improving the process and should specify the personnel responsible for each of these activities. Feedback process governance should include the following:

- Specify why the process is effective and efficient
- State the benefit of the process
- Specify the process owners
- Specify roles and responsibilities within the process
- Encourage participation among all stakeholders of the feedback process in the effective management and improvement of the process, by specifying areas where the feedback process is not meeting their needs and suggesting methods of improvement.
- Should encourage transparency and ensure the process is conducted in accordance to the set rules and regulations. The feedback information should also be easily available and accessible to its users. Detail information should be provided and presented in an understandable format for its users.
- The governance procedure must specify the accountabilities within the process. For example who is accountable to whom? However, accountability cannot be enforced if the process lacks transparency.
- There should be minimal hand-offs in the process procedure. This means that a limited number of people should be taking responsibility for handling the feedback process, in order to avoid confusion and delays in the process.

Braganza and Lambert, (2000) developed a process governance framework, based on two perspectives: process and governance. According to this framework, people's roles, responsibilities and personal rewards are set out on a divisional, functional or departmental basis. The governance framework suggests that people's roles, responsibilities and targets are aligned to a function and process perspective. The framework requires managers to make it explicit where responsibility for information rests.

According to this framework, function or departmental managers in a process must allocate responsibility for the activities that form the process. For example, by clarifying the level of discretion of each individual. In addition to responsibilities, business leaders establish measures against which the performance of the activities can be assessed, for example, time taken to repair

an appliance, frequency, cost, and quality. The governance profile for each process will evolve over a period of time in response to changes in the environment, strategic direction and stakeholders' expectations. The term 'activity' incorporates the work, roles, and responsibilities and tasks that one or more individuals perform as their 'day job'.

5.9.1 Developing process capability

In order to develop process capability Zollo and Winter (2002) suggested that an organisation must systematically create and modify its operational activities in the quest for improved effectiveness. This would enable an organisation to respond adequately to new competitive challenges. In the context of this research, to foster an environment of continuous feedback, learning and improvement, the organisation must possess and grow superior process management capabilities by understanding the data capture, sense making operation and how the information is disseminated for use in making product design changes. This is required for the organisation to succeed in their quest for product improvement and also in maintaining their special capabilities in their competitive environment. Teece *et al.*, (1997) considers this approach as a dynamic capability which requires the organisation to build, integrate and re-structure their competencies to address the changing environment needs.

To exploit the learning capabilities of the feedback process, there must be cross functional communication as discussed in an earlier section. That means field failure data must be monitored immediately after product launch and failure data gathered from the field must be quickly brought to the attention of the development team. This field data can be used to support the improvement to products and components and the development of new ones. According to Sacconi *et al.*, (2006) field data feedback can be used to support marketing, sales and promotional activities. In addition it can be used to validate product performance (Molenaar *et al.*, 2002). Developing process capability requires improved application tools for recording and storing field data, as well as skilled service engineers who understand how the system works and what information is required from the field. Without this, the process will not be able to aid product quality and reliability improvement. Stakeholders must be able to generate and use the field data effectively whenever it is required. The ability and performance of the team responsible for driving the process also enhances the process capability to meet its intended function.

5.9.2 Ownership

A process should have a clearly defined owner who reviews the process performance and is responsible for the continuous improvement of the process Lee and Dale (1998). The feedback process should have some designated process owners who are responsible for managing activities within the process and an appointed person who will oversee the overall process. The appointed process overseer should be responsible for the monitoring of the process performance and authorising process improvements. As the feedback process cuts across different functions within the organisation, the authority over the process becomes unclear, therefore it is important have overall process ownership, whose responsibility should include; leading the coordination between the process stakeholders and across the product improvement process, disseminate information, in other words making sure the right information is

available and passed on to the necessary stakeholders at the right time. The responsibilities of the process owner should include ensuring that the process is properly documented, maintained, improved and updated when appropriate. Process owners should monitor performance and identify gaps through regular reviews and then close the gaps. Regular inspection of the process enables the reduction of variability in the process (Lee and Dale, 1998).

5.9.3 Co-ordination

Roles, responsibilities and organisational structure should be defined, and where appropriate, training and development needs must be identified (McAdam, 1996). Hence, activities performed in different functions need to be co-ordinated and integrated in a business process, which satisfies stakeholder expectations.

The co-ordination of the feedback process should begin by considering the activities in the process and referencing them to business objectives to be achieved as well as the stakeholders' expectations of the process. As functional activities are co-ordinated and integrated in each cross-functional process, management need to understand the basis of integrating the activities (Braganza and Lambert, 2000)

5.9.4 The role of quality control

The role of quality control is to keep the process in check and thus make the feedback process more efficient and effective. To stabilise a process, it is necessary to evaluate and control its operation. Quality control should be established at the three stages of the feedback process. The head of the functional units involved in the feedback process should be responsible for the quality control of the activities conducted by their units towards the feedback process. The main objective of quality control of the feedback process is to identify operational techniques for detecting, recording and taking action to eliminate quality problems in the feedback process. Two types of quality control can be established within the feedback process, they are: self-control or team control. According to Juran (1992) individual quality control is effective only if the individuals know what they are doing. The alternative to this is team control which involves assigning responsibility for quality control to a team. This can also be used in combination with self control. In other words, each individual can be responsible for checking the quality of their own work and the assigned team would be responsible for the overall quality of the feedback process.

5.9.5 Performance measurement

The goal of performance measurement is to ensure that the feedback process is operating at its maximum level of added value. Therefore, the performance of the feedback process must be evaluated and outcome from it should be feedback to management of the process, in order to improve the process and sustain its effectiveness to the overall product development process. Performance measurement has been described as a method of quantifying the efficiency and effectiveness of a process (Neely *et al.*, 1995; Kumar and Harms, 2004). A clear definition of effectiveness and efficiency is provided in Vuorinen *et al.*, (1998); they defined efficiency as "the degree to which an activity generates a given quantity of outputs with minimum use of inputs" whilst effectiveness is the ability to attain a goal or purpose". In other words, effectiveness is about doing the right things and efficiency is about doing things right. In the context of this research

both the effectiveness and efficiency of the feedback process performance must be measured so that limitations in the process can be identified and necessary action can be taken to ensure an improved process that meets its users' needs. Measurements are of little value if they do not help to evaluate performance and point out areas for improvement. Since the current feedback process is not formalised, the need to measure how well it is performing cannot be realised. Process performance needs to be measured to understand the outcome of the process. It is an essential aspect of process improvement which would help an organisation to focus on the important characteristics of operations, as well as decide on the problem areas to focus on for improvement (Grunberg, 2004). Sinclair and Zairi (1995) identified the importance of performance measurement; to mention a few, this includes effective and efficient planning, control and evaluation, managing change, providing precise communication and making improvements.

Measurement serves as a mechanism for further refinement of the process and if necessary, for improving and optimising the overall output of product improvement. The current feedback process does not measure the performance of its activities. Neely *et al.*, (1995) asserted that an organisation should measure their process in order to know their current situation, know how they are improving, and enable them make comparison with their competitors. Nanni *et al.*, (1990) described performance measures as part of a feedback loop which "controls operations against a specific value". Hronec (1993) stated that performance measure is vital for quantifying how well the activities within a process or the output derived from a process achieve a specified goal. Sinclair and Zairi (1995) stated that process measures monitor the activities of a process and motivate the users of the process. In the context of the case company it is important for the organisation to measure how well the feedback process is meeting the requirements of its users. In order to maintain the effectiveness of the feedback process it must be continually monitored and optimised to suit changing business conditions.

The performance of the feedback process can be measured by surveying users about the quality of the content and the timeliness of the feedback information. Quality of the feedback includes accuracy, reliability, and level of details, relevancy and understandability. Kaplan (1991) asserted that an effective performance measurement should provide timely and accurate feedback on the efficiency and effectiveness of the process operation. It is evident from the literature that in order to evaluate the performance of the feedback process in detail, there must be different levels of analysis such as the actual process, activities and the functional units involved in the feedback, as well as different performance dimensions such as the effectiveness and efficiency of the feedback process. In particular when considering measuring the performance of after sales service, Sacconi *et al.*, (2006) argue different levels of analysis and performance dimension needs to be deliberated upon. Sinclair and Zairi (1995) suggested that process performance measures should include the inputs, process and outputs. Sinclair (1994), in his research, further suggested eleven steps in managing and measuring a process. A number of authors have described methods of designing performance measures (Lea and Parker, 1989; Lynch and Cross, 1991; Fortuin, 1988) amongst which Neely *et al.*, (1997) developed a framework that summarises elements that constitute a good performance measure.

Antecedent-Governance	
Key attributes	Guidelines
Developing Process Capabilities	<ul style="list-style-type: none"> Define the feedback process and establish its boundaries and relationships with other business processes.
Ownership	<ul style="list-style-type: none"> Ascertain process owners/ stakeholders, describe their roles and responsibilities and the chain of command within the process structure.
Quality Control	<ul style="list-style-type: none"> Develop guidelines for process, policy and procedural changes. The feedback process should be subject to regular review and quality checks. Appoint an individual or team to oversee that the new feedback process is institutionalised over time. Establish a continuous process improvement program to minimise non-value added activities and work duplication.
Performance Measurement	<ul style="list-style-type: none"> Data from the field should be used to measure product performance, to identify failure trends and highlight problems that need to be resolved quickly before they escalate to serious errors or accidents. The field feedback process should be driven by the search for improvement. This can be achieved by doing the following: <ul style="list-style-type: none"> Evaluate the performance of the feedback process. Identify performance indicators. Establish process improvement teams to review the feedback process and improve process effectiveness and efficiency. Action regular updates to the feedback process. Integrate lessons learnt into product development process.

5.10 Chapter Summary

The chapter presented a framework of antecedents (pre-conditions) of effective service-to-design field failure feedback process, which are grouped into four aspects; its **nature, a structured operational process, integrative mechanisms and governance**. This framework seeks to ensure the smooth running of the process operations and its governance which includes procedures for the management of the process. The chapter gave a detailed description of each of these antecedents whilst highlighting key factors to be considered under each antecedent when conducting the field failure feedback process. It also

suggests that the field feedback process must be conducted and managed from as a holistic perspective to ensure its long-term efficiency and effectiveness. A number of key guidelines have also been given to establish the key learning points, which act as implementation aids for each antecedent.

CHAPTER 6: VALIDATION OF PROPOSED FRAMEWORK

This chapter describes the conceptual validation of the proposed framework discussed in chapter 5. The purpose of research validation is to provide confidence that the research conducted is tested for its merit, to refine proposed model as appropriate and ensure that a valid contribution to knowledge is identified.

6.1 Introduction

Easterby-Smith *et al.*, (2002) established that to assure validity, reliability and generalisability of a research study it must incorporate the experiences of experts in the research setting whilst showing some relevance to other research settings. The validation of the conceptual framework was conducted in two separate and different industrial settings. The first validation exercise was conducted within the sponsoring company (Valiant Group) used in earlier stages of this research and the second was within a vacuum equipment manufacturer, which would be referred to in this thesis as Vacuum-Co. In view of the fact that the empirical findings that led to the development of the conceptual framework were mainly from the sponsoring company, it was decided that an additional validation session with experts from one other company would be conducted to enhance the external validity.

6.2 Design of the validation exercise

The validation exercise set some objectives and developed an interview schedule to capture the opinion of experts and facilitate the achievement of the evaluation process. The objectives were as follows:

- To gauge relevance of proposed conceptual framework to existing service-to-design feedback process.
- To assess the applicability of the framework in the context of the specific organisation
 - What potential benefits might it provide to the companys' existing service-to-design feedback process?
 - What potential challenges might they expect in implementing the framework?
- Identify key aspects of implementation effort if the framework were to be adopted in practise.
- To determine necessary changes required to further refine the conceptual framework.

Industrial experts (service manager and product design engineer) from the Vacuum-co company were contacted to participate in the validation exercise. See appendix VI for the request letter sent to the company.

Table 6-1: Profile of companies/experts used for the validation of the conceptual framework

	Valiant Group	Vacuum-Co
Size	10,000	3,600
Industrial sector	HVAC	Semi-conductors
Business/Product	Heating equipment manufacturer/boilers	Vacuum pump manufacturer
Product family	Series of variants	Series of variants
Development time	1 year	3 years
Participating Team	Quality Service	Design Service
No of people interviewed	2	2
Role of experts Interviewed	R&D Quality planning manager Service manager	Senior designer Service product manager UK Sites service manager

6.3 Validation Methods

This section defines the criteria for evaluating the proposed field failure feedback framework. According to Platt (2003) criteria for assessing a process based framework should include:

- Usability- The usability assessment tests the ease of use and understanding of the framework by its different stakeholders.
- Usefulness- The usefulness criterion assesses the effectiveness of the framework on improving the existing feedback process, experts' opinion on the usefulness of the framework contents.
- Practicality-The assessment of practicality tests the realism of implementing the framework as well as the implication for practise, benefits and possible values that can be achieved if implemented.

Each criterion would be discussed in detail in later sections.

As discussed in the research methodology chapter, a case study approach was used for the validation exercises. The interviews were initiated with a brief introduction of the research study, which includes methods used, description of key findings from the empirical study and the derivation of the proposed framework. The diagram of the proposed conceptual framework as illustrated in figure 6-1 was presented to the interviewees and formed the basis of the validation discussion of the antecedents of an effective feedback process from service-to-design for the purpose of product improvement as explained in chapter 5.

After the explanation of each antecedent, participants were prompted to comment on its applicability in the context of their organisation and its usefulness in improving their existing field feedback process. Each validation interview lasted for approximately two hours. Figure 6-1 below shows the diagram of the overall conceptual framework of effective service-to-design feedback process. The sequence of discussion of the conceptual framework is as follows:

- Nature of process – involves the overall process characteristics
- Process operations and structure – involves the process of collecting, analysing and utilising the field data
- Integrating mechanisms – involves the communication tools and techniques for ensuring a seamless collaboration
- Governance – refers to taking ownership and control of the process

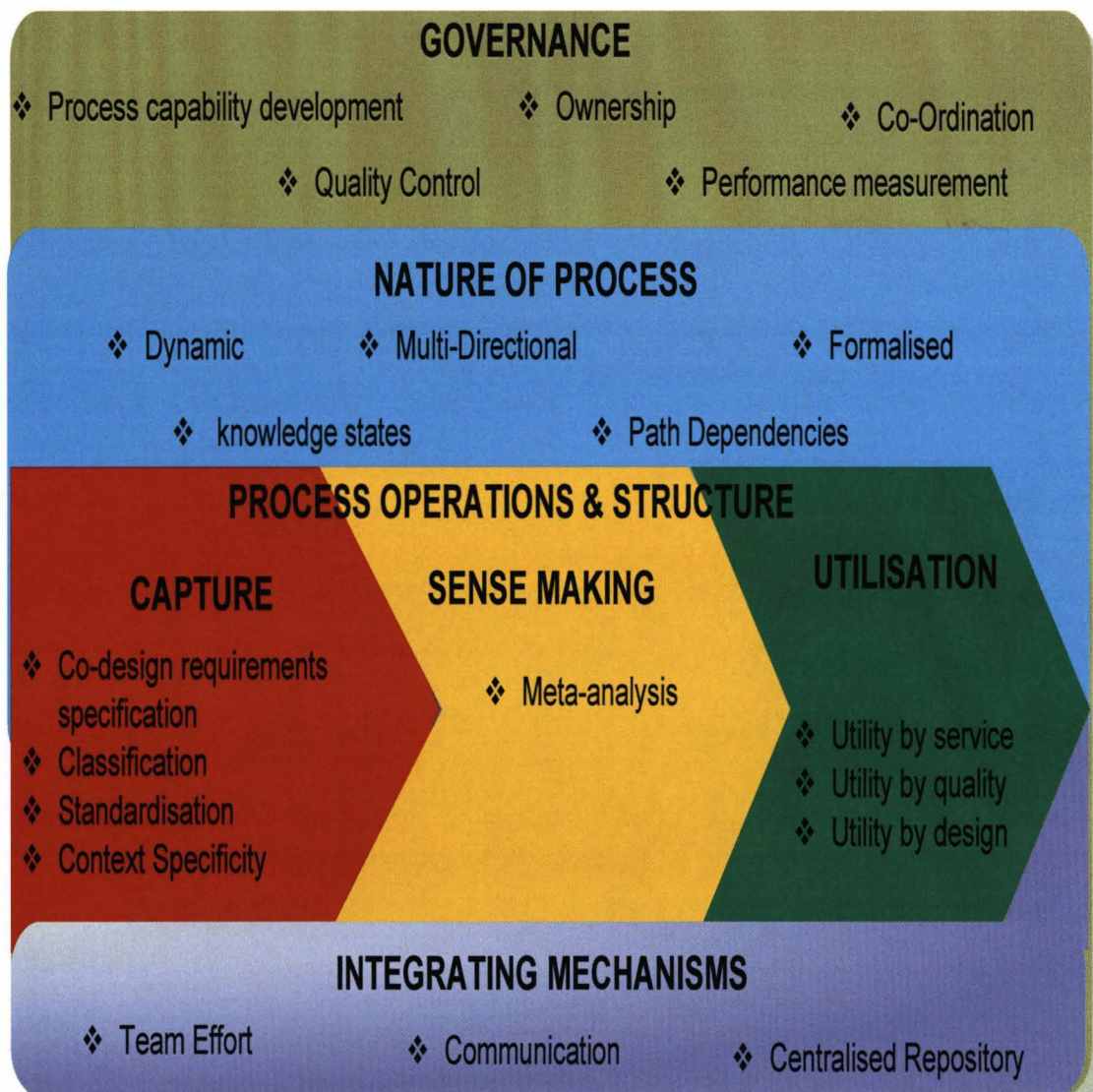


Figure 6-1: Conceptual framework of effective service-design feedback process

6.4 Emerging themes

Table 6-2 and 6-3 respectively presents a summary of the key issues that emerged from the validation exercise and the quotations from the interviewees relating to the three criteria used for the assessment of the proposed conceptual framework. Further description of criteria will be discussed in later sections.

Table 6-2: Key issues emerging from the validation exercise

Key Issues	Valiant Group	Quotes	Vacuum-Co	Quotes
Overall Process	<ul style="list-style-type: none"> • Must be easy to use. • Must be dynamic. • Formalised structure • Consider should impact of new changes 	<ul style="list-style-type: none"> • <i>"The process must constantly change to fit the current production requirements"</i> • <i>"The formalised structure proposed by the framework would encourage consistency and better understanding of the feedback process"</i> Service manager & Quality planning manager • <i>"Any changes that are made would have to have training implication".</i> Service manager • <i>"There needs to be a guideline set within the system, about the change and effects of the changes".</i> Quality planning manager 	<ul style="list-style-type: none"> • Must be easy to use • Must be dynamic • Must be consistent 	<ul style="list-style-type: none"> • <i>"The framework must be simple enough for use by all the people involved in the feedback process"</i> Service Manager • <i>"The system should change as things improve with knowledge"</i> Service Manager • <i>"Training on how to use the tools is important to drive consistency"</i> Service Manager • <i>"Make the feedback process as user friendly as possible. Don't underestimate the fact that people have more things to do. The system has to be fast and slick and above all easy to use".</i> Senior designer •
Critical activity	<ul style="list-style-type: none"> • Field feedback/feed forward of field data. • Identification of root causes 	<ul style="list-style-type: none"> • <i>"If the designers are using it for making design improvement, they should feed some of the information back to the service engineer."</i> Service manager • <i>"The suggestion to provide guidance to aid service engineer on how to identify and record root causes of field failures would encourage the recording of useful information"</i> Quality planning manager. • <i>"The major work of recording failure data should be at the root cause identification stage, the rest of the question should be about just describing parts".</i> Service manager 	<ul style="list-style-type: none"> • Field data recording • Analysis of field data • Identification of root causes 	<ul style="list-style-type: none"> • <i>"The importance of the quality of the data is good. Standardisation and training on how to use the reporting tool is quite important".</i> • <i>"Because the data capture template is co-designed by process stakeholders, relevant information would be recorded and the analysis of the data would have a common interpretation"</i>

Table 6-3: Key issues emerging from the validation exercise

Key Issues	Valiant Group	Quotes	Vacuum-Co	Quotes
Process Effectiveness	<ul style="list-style-type: none"> • Cross functional team collaboration. • Stakeholders must be aware of the structure & management of the process. • Improved quality of field data capture 	<ul style="list-style-type: none"> • <i>"Having regular meetings or some sort of direct communication between the feedback process functional teams particularly between service and design is vital"</i> Service/Quality Manager • <i>"The framework would supports early involvement of service in product improvement function e:g Getting service involved from the early stages of the field data analysis such as during FMEA process"</i> Quality Manager • <i>"The framework would encourage the functional teams to have some level of understanding about roles and responsibilities each function contributes to the overall feedback process".</i> Service Manager • <i>"The effective use of the field data is only as good as the information recorded. Co-designing the job worksheet for recording field data would help in assuring more detailed and relevant quality data is recorded".</i> 	<ul style="list-style-type: none"> • Consider skills and experiences of stakeholders • Capture more contextual field information. • Requires cross functional collaboration 	<ul style="list-style-type: none"> • <i>"The framework could facilitate service engineers to operate at the same level as design engineers in terms of intimate understanding of why equipment was design in a particular way through cross function collaboration. Service manager,</i> • <i>"There is an element of truth in the need for service engineers to capture not just component related failure but information on the operating environment of the appliance that may have resulted to the failure. Senior designer</i> • <i>"Communication from design to service, to give feedback or progress on their attempt to finding solutions to problems identified in the field".</i> • <i>"The quality of information has a major impact on the effectiveness of this feedback" senior designer.</i>
Suggestion for improvement to the framework	<ul style="list-style-type: none"> • Training issues 	<ul style="list-style-type: none"> • <i>"The brightest service engineer is able to fix a problem but not able to identify the root cause. But if you train him on how to identify the root cause, he would be skilled to do so. Training is important for preparation of implementation"</i> Service Manager • <i>"The framework will refocus peoples' attention on quality"</i> Quality Manager 	<ul style="list-style-type: none"> • Consider training issues 	<ul style="list-style-type: none"> • <i>"The level of education could be a barrier that is preventing service engineers in recording quality information".</i> • <i>"The framework might close the gap in the level of operation between service and design".</i>

In table 6.3 below, some of the perspective of the experts from the two case companies is presented. These quotes reflect an expert's opinion on the proposed framework using three assessment criteria.

Table 6-4: Interviewee quotations on the validation assessment criteria

Criteria	Valiant Group	Vacuum-Co
Usefulness	<ul style="list-style-type: none"> • <i>"Guidelines set within the process would provide directions for successful execution of the process"</i> • <i>"Facilitates multi-directional communication"</i> • <i>"Establishes a formalised process".</i> • <i>"Presents an holistic view of the process"</i> 	<ul style="list-style-type: none"> • <i>"Co-designed requirement specification would enable stakeholders needs to be met"</i> • <i>"Field data feedback framework is useful because it encourages cross functional communication"</i> • <i>"Presents a complete view of the process"</i> • <i>"establishes an understanding of the various roles and skill set required for the process effective"</i>
Usability	<ul style="list-style-type: none"> • <i>"Requires team effort"</i> • <i>"Requires training and promotion of the benefits of the new system".</i> 	<ul style="list-style-type: none"> • <i>"Sense making would be easier due to the unified interpretation of data"</i> • <i>"Training on how to use the improved process or field data reporting tool is important"</i>
Practicality	<ul style="list-style-type: none"> • <i>"Any changes made to the feedback process must have training implications"</i> • <i>"New improvement to the process must have less impact on the historic data".</i> • <i>"Closes the gap in the feedback loop".</i> • <i>"Provides guidelines for effective feedback process management"</i> 	<ul style="list-style-type: none"> • <i>"Field data will never be enough for every situation"</i> • <i>"Interdisciplinary immersion is quite difficult to do in an industrial environment"</i> • <i>"Must be easy to implement with less minimal disruption to business operation and less time consuming effort".</i> • <i>"Time and efficiency is very important"</i> • <i>"Encourages the capture of relevant data otherwise there is no point in capturing field data".</i> • <i>"Bridges the gap in communication"</i>

6.5 Case Study 1: Valiant Group experts' inferences

The experts both agreed that the proposed framework is capable of improving the current feedback process. They also agreed that the development of co-specification would create an understanding of what is required by both design

and service engineers in order to fulfil their functional duties. For example, design engineers require the root causes of a failed component. This should be reflected in the data capture system, the root cause question should be at the front end of the data recording template. There should be guidance at the front end that helps the service engineer in identifying the root cause and recording accurate data. The work of recording failure data should be at the root cause identification stage, the rest of the question should be about just describing parts. Training should also be given to service engineers on identifying the root cause.

Both experts agreed that the terminology used for failure description should be standardised across the organisation because of language barrier. For example, if various terminologies are used, it will be difficult for someone in Germany, who has limited understanding of English language, to search and use the failure database which they will find difficult to use.

Experts also agreed that feedback should be a two way communication between service and design. According to the service manager:

"The framework would encourage collaborative communications between functions. And allow information about the field data to be available in both ways." Service Manager, Valiant Group

It is believed that feedback from designers would encourage service engineers to improve on the quality of data captured.

Both experts are sceptical about giving service engineers direct telephone contact numbers of designers; it is believed that the facility will be abused by service engineers.

Rather than the service engineers calling designers directly, it was recommended that they contact product managers in the R&D department instead on any issues they are experiencing in the field regarding a particular product. However, it is essential to set some conditions on the type of issues that require contacting the product manager. Product managers should be the link between service and R&D team.

In order for the feedback process to be dynamic as the product changes the system needs to be constantly changed to fit the current production requirement. However, any changes that are made would have training and awareness implications. There is a need to make sure people understand the need and usefulness of the new system.

The experts established that the overall improvement to the feedback process should be done gradually. Radical implementation should be avoided as there are training implications involved in the usability of the improved system.

6.6 Case Study 2: Vacuum-Co

6.6.1 Case Selection

Vacuum-co was selected as a suitable company for this case study because of its similarities with Valiant Group, such as the following:

- Large multinational organisation
- Manufactures products that require service support
- Has its own service departments
- It has a multifunctional business process model that supports its new product development projects

6.6.2 Case Background

Vacuum-co is a global supplier of integrated solutions for the manufacture of semiconductors, flat panel displays, LEDs and solar cells and vacuum technology for industrial, scientific, process and R&D applications. Vacuum-co has a turnover of US\$1billion and employs over 3,600 people worldwide in the design, manufacture and support of high technology vacuum and exhaust management equipment. The company is the largest vacuum supplier and second largest sub-systems equipment supplier to the global semiconductor industry and supplies all of the major semiconductor manufacturers. This equipment is serviced through dedicated key customer management teams in each area of the world.

Service support is delivered locally and helps customers to get the most out of their equipment through service offerings such as repairing a single product, to managing an entire facility through field and on-site services, equipment repairs and product exchanges, and applications expertise via equipment health checks, technical support and technical training. The company's full service support partnership includes facilities design and management and OEM services, including a tailored service package to meet customers' needs. Service engineers often visit the customers' site to carry out preventive maintenance, breakdown or effect repairs. There are onsite service engineers at the site of two of their biggest customers. The company has a service hub station where UK customers send faulty pumps or sometimes send pumps for planned maintenance. Faulty pumps are mostly fixed quite easily on site, or sometimes replaced.

Technical queries are fed back to the service manager or field supervisor. Customers' complaints are logged if it is warranty related, requires part replacement or a field engineer visit, otherwise it is not recorded. Field failure

data are recorded on a sap system. However, this information is mostly used when service support is facing difficulty in resolving a problem. There seems to be no standardised feedback process within the company. According to the service manager:

"It is difficult to say that the feedback process is good or not because I do not get feedback on the data recorded in the sap system" Senior Designer, Vacuum-Co.

Every three months design engineers are invited to attend a strip conducted at the service hub. The strip involves stripping down a product into pieces in order to identify possible failure root causes. Designers within Vacuum-Co do not get feedback from service. According to the service manager:

"Communication between service and design engineers happens but generally limited to when there is a crisis" (Service manager, Vacuum-Co).

Feedback on product failures is directed towards certain people such as the senior management within the company. Other informal means of feedback is through personal contacts by talking to people from the assembly plant. There is no formal field failure feedback process. Finding information is based on an individual knowledge and knowing who to ask or where to look for the required information. During the interview session, to aid the participants in understanding the proposed framework and some of the benefits that can be obtained from it, two case scenarios were presented to support the discussion. The first scenario gave a brief description on the monitoring of field feedback process and the need for improvement whilst the second scenario gave a description of difficulties with field data and the need for improvement.

6.6.3 Experts inferences

Both participants from Vacuum-Co gave a positive feedback on the proposed framework. The following are some of the comments made:

"The framework would enable us to refocus our attention on quality, service problems and manufacturing, if we should implement this framework, it will refocus our attention on where we should be and encourage functional teams to work together" (Design manager, Vacuum-Co).

At present the design and service team work independently and the level of communication between both teams is minimal. The proposed framework emphasises the importance of communication across the various stakeholders of the feedback process in order for it to be effective.

Both respondents agreed that the structure of an ideal feedback process must be dynamic, multi-directional and formalised in nature for it to be effective. According to the Design manager from Vacuum-Co;

"I certainly believe all designers should spend a couple of days every year at the factory, so they can experience what it is like to actually put the product together. They should

also visit a customer site. That would enable them to understand better some the benefits provided as well as difficulties experienced by them".

The formalisation of the feedback process also appeared to be important. Having no structured approach in place means that the process will be performed on an ad-hoc basis, using people's individual knowledge.

"By trying to formalise the process it will make information easier to sort through" (Design manager, Vacuum-Co).

An improved data capturing system would enable traceability, where data entered into the field database can be traced back to the service engineer if there is a need for more details on the field failure data that was recorded.

"Once data capturing is improved, it would reflect on the analysis and therefore make it easier. If there is something in data that is very relevant or unusual, you can follow up on it, by asking the service engineer in question what actually happened" (Design manager, Vacuum-Co).

The case validation participants acknowledge that field failure feedback from service-to-design is vital, otherwise designers would design what they think is needed rather than what the customer needs based on actual field experiences. In terms of data captured from the field, respondents agreed that failure is not always component related. They support the idea proposed by the framework to capture both component and contextual related field failure data, such as, the operating environment of the appliance that may have resulted to the failure. For example, the quality of cooling water is one of the ways a pump can be damaged. The experts also agreed it is important to the following:

- Make failure data accessible and readable (e.g. link from design manuals to service database)
- Provide traceability: link data to the service engineer to allow follow-up
- Free text field is important in service field data capturing system; however it should include spell checks and prompt texts

6.7 Validation assessment key findings

Experts' opinions were obtained from both industrial visits and this was used in identifying some useful findings based on the set criteria usability, practicality and usefulness, as discussed in section 6.3. Positive feedback was received from both industrial case studies. The following are the descriptions of the criteria are given below.

6.7.1 Usability

All the participants gave positive feedback on the usability of the proposed conceptual framework. Usability of the proposed framework requires both team

and individual efforts. For example, service engineers' awareness of the need for recording quality field data means that they make extra effort in ensuring that the information recorded by them meets the requirements of its subsequent failure data analysis and for eventually making design changes aimed at improving product quality and reliability. In terms of team effort the co-design requirement specification would ensure the needs of the process stakeholders are taken into consideration when designing the template to be used in recording field data. The format of the template would limit the possibility of recording irrelevant data that is not fit for use during product improvement process.

The participants also agreed that the framework provides a better understanding of what should constitute a feedback process from service-to-design in order for it to be effective. It was emphasised by the design manager in Vacuum-Co that when designing the system, the work load of the users should not be underestimated; therefore understanding users' needs in terms of having a fast and easy to use system must be designed into the process. Usability of the proposed framework highlights the need to train users, so they have a common understanding of what is involved in the process. It was also suggested by the design manager in Vacuum-Co that the field database should fit in quite well with the front page of the intranet so that knowledge can be shared across cross functional teams.

6.7.2 Usefulness

Again, a positive feedback was given on the overall usefulness of the proposed framework. Opinions of interviewees from both case companies indicated that the benefits of the proposed framework could be extensive if users were trained on how to exploit their new system in making informed decisions for product improvement. According to the design manager from Vacuum-Co *"if the framework is to be implemented within their company, one of the challenges is to make it as user friendly as possible"*. The framework is seen to be very useful because it facilitates having a structured and formalised process, encourages effective communication, process monitoring and control. The framework is viewed by the participants from both case studies as a useful approach capable of significantly improving the existing feedback process from service-to-design within their individual organisation. It is believed that it would provide substantial benefit to their functional responsibilities. The framework provides a structure for the process operation whilst establishing the effective distribution of information via integrated communication mechanisms to assure the effectiveness of the process. The co-design requirement specification might save time as well as resources used in investigating the root cause of failure, as requirements of each stakeholder are known and embedded in the system.

Participants from both case companies agreed that a formalised process would maintain consistency in the process.

6.7.3 Practicality

The practicality of implementing this framework was judged to provide significant benefits that would improve existing field feedback process. Interviewees from both case companies asserted that the framework provided a holistic view, which included the structure and management of the process as well as the stages involved in the process operations. Although the framework supports regular and more direct communication between service and design, one potential limitation that was highlighted is that if service engineers have access to designers direct contact number, the system may be abused through service engineers constantly contacting designers on every little problem they have, therefore designers' might resort to performing service duties instead of designing. All participants agreed that formalising the process would eliminate inconsistencies especially in the failure recording process.

The framework encourages the gathering of more specific information from the field. Participants agreed that the co-design specification factor would enable users of the framework to establish the goal of what they intend to achieve from the feedback process. By improving the front end of the data capturing process, the analysis of the field data becomes easier, because the relevant field data would have been captured.

From the point of view of the interviewees in Valiant Group, implementation of the proposed framework requires training stakeholders on how to use the new system and how to execute the newly improved process.

In practise, the proposed framework could be viewed as an approach for bridging the gap in communication between service and design taking into consideration their skill sets, experiences of field problems and level of education.

6.8 Suggestions for improvements to the proposed framework

Interviewees from both case companies observed that training and the skill set of the stakeholders were not considered in the framework. These issues are considered to be important in facilitating the successful implementation of the proposed framework. According to the service manager from Valiant Group , any changes to the feedback process must have a training implication.

"You have to make sure people understood the training" (service manager, Valiant Group).

In other words users of the feedback process must be trained to understand the impact of the new changes. This can be achieved by developing a set of

guidelines that would support users as the changes take effect. The design manager also emphasised the importance of training and the level of education of the users of the process. As he commented:

"Training and education is very important. I think the information that is included in the database is only as good as the person that recorded it and if they have a different understanding, then you will have different information"

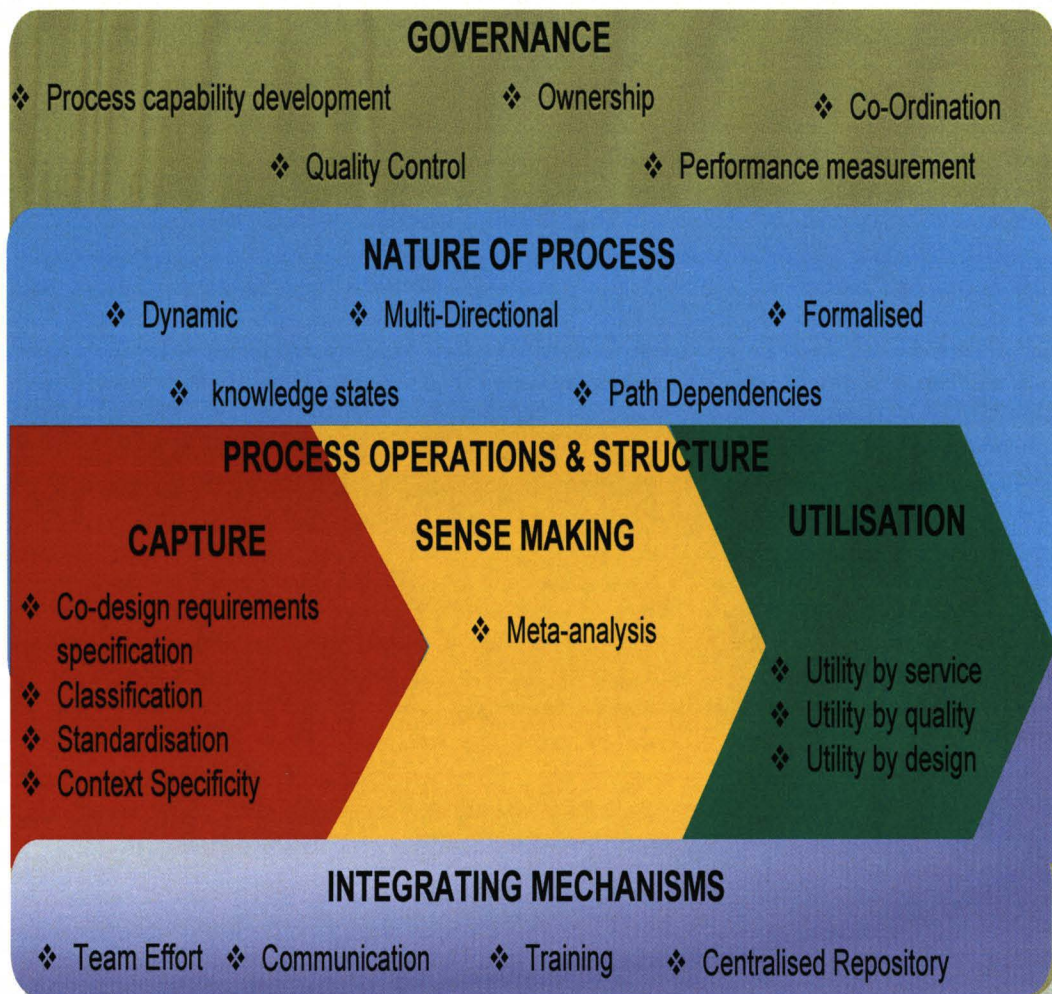
The issue of training was not emphasised in the proposed framework, however, it will be considered when refining the framework. As stated by the service manager:

"The only thing that the framework did not cover is the education level; they are not all graduate engineers. The field service engineers typically know what is wrong with a product and can fix it whilst they don't understand the thermo-characteristics of the product, which the designers have knowledge of. The service engineers and the designers are not the same. If the service engineers were to be like the designers, they would be doing designers job".

The degree of difficulty that can be experienced in implementing the framework can be limited if there is extensive training in place. Training is very important in keeping users up-to-date with the new process and ensuring it is well understood. There is a gap between the level in which service and design engineers are operating. Service engineers are not operating at the same level as design engineers in terms of intimate understanding of why equipment was designed in a particular way or why a control system operates in a particular way. Service engineers are trained to fix problems.

6.9 Framework refinement

As suggested by the validation exercise training should be included in the proposed framework as part of the mechanism for integrating the field feedback operation. In order to maximise effectiveness, it is necessary for training and development to be kept relevant to each functions in the field feedback process. Training is essential for ensuring the unrelenting high performance of the feedback process, the improvement of personnel's; and for increased morale and motivation. When considering the implementation of the framework, feedback from the validation of the framework as shown that training is important. The process stakeholders must understand the new feedback process-what it is, how it works, how it impacts their work, their customers (internal or external) and the overall product development process. However the cost of training might determine its frequency but this cost should not deter the need for training, as the cost of a potential problem could be greater. Training should also be targeted at specific function of the feedback process that would help the different functional team make valuable contribute to overall efficiency and effectiveness of the process operation. Figure 6-2 below presents the refined framework. For example, by training service engineer on product design issues, they would gain significant opportunity in learning more about the product technicality, which would in turn help them when carrying out repairs and reporting on failures in the field.



6.10 Limitation of the validation from a methodological perspective

One of the limitations of the validation method is the researcher selection of the participant of the validation exercise. The validation of the framework was carried out with some of the experts who were consulted for the initial research data collection, using the same experts for the validation could increase research bias. The framework could be further validated by testing it in wider industrial contexts and across a large sample to increase its generalisability. Due to nature of the validation method, it is quite difficult to measure the exact impact that the use of the framework would have if implemented in a real world setting as the researcher could only rely on the feedback provided by the experts. Another limitation is that a single method was used for validating the framework, the credibility of the experts opinion could have been enhanced by using another method for triangulation.

6.11 Summary of the validation case study

To determine the potential of the proposed framework as a useful and effective field failure feedback process from service-to-design for product improvement purpose, a case study approach was employed for testing the validity of the proposed framework.

The proposed framework consists of antecedents for an effective feedback process which is suited for organisations of any size. The participants have indicated that the contents of the framework address vital issues. Expert opinions suggest that the proposed framework addresses some of the important factors that would enable an effective feedback process from service-to-design for product improvement purpose. The participant believes the framework encourages the need to focus on the quality of field data captured in order to improve its usefulness in the design process. Both case companies agreed that if properly implemented the framework would significantly improve the effectiveness of their feedback process.

Suggestions for improvements were taken into consideration; necessary modifications were carried out to incorporate these suggestions before producing the final version of the proposed feedback framework. In conclusion the chapter has provided a detailed account of the validation case studies, expert opinions and its subsequent outcomes. It has also demonstrated the feasibility, usability, usefulness and relevance of proposed framework. Therefore, this chapter has shown how objective three of this thesis, as set out in section 3.1 has been pursued. It has been achieved through the use of case studies and interviews to obtain industrial expert opinions as discussed in the chapter. Overall, a positive feedback was given by the participants of the validation exercise. Given that this exercise was to validate the conceptual ideas of the proposed framework, further research into the usefulness (utility) and the implications for practise can be explored through the actual implementation of the framework within a case company.

CHAPTER 7: CONCLUSIONS

This research embarked on the development of a conceptual framework to guide practitioners in pursuit of feedback of product field failures from service-to-design for the purpose of product improvement. This chapter illustrates how the research aim and objectives have been met and draws conclusions from the research findings. The contributions to knowledge made by the research are also presented. Finally the limitations and areas for future research are identified.

7.1 Research Objectives

The aim of the research as stated in chapter 1 of this thesis is:

“To develop a conceptual framework for an effective field failure feedback process from service-to-design”.

This aim was achieved through the research objectives as follows:

- To review extant literature and identify the salient issues associated with feedback from service-to-design in the context of product improvement.
- To empirically inform theoretical findings to develop a coherent conceptual framework for field failure feedback process from service-to-design.
- To further validate the framework via case studies.

The research objectives provided the underlying structure for the research presented in this thesis. The following sections discuss how the research objectives were met and present the conclusions that have been drawn from the study. The fulfilment of these objectives represents a contribution to knowledge within the extant literature. This body of evidence lacks an understanding of the antecedents that is, factors that constitute a set of conditions for the effective management and organisation of product field failure feedback from service-to-design.

7.1.1 Research objective 1

To review extant literature and understand the salient issues associated with feedback from service-to-design in the context of product improvement.

A review of existing related academic research published in peer reviewed journals and conference articles were conducted. This review focused on understanding the field failure feedback process in the context of product improvement particularly in terms of quality and reliability. It examined its importance, the benefits organisations derive from service-to-design field feedback, existing models of product field feedback, in particular, identifying the

flow of information between the two functional disciplines and the types of field data required for product quality and reliability improvement. The review also examined the analysis of field data using techniques such as FMEA. The major findings from the literature include:

- Product development processes suffer from pressures associated with allocation of time and resources, time to market, increasing customer demands and increasing product complexity, which makes it difficult for organisations to predict how a product will perform when in use.
- The field data concerning field failures passed on from the service-to-design function is often inadequate for the purposes of product improvement. For example, the failure data may be inappropriately categorised and formatted. Therefore the quality of the field data is often very poor and missing vital information such as the root cause of a failure. If the quality of the field data is improved, it would be more useful in application and so more and effective in the product design process.
- The extant literature suggested that feedback from the field is very important to business operations. There is a dearth of research on feedback process from service-to-design function, what operations it constitutes and how it should be managed and organised. Available research on feedback of field failures has mainly focused on improving the speed and quality of information for design and development without specifying which information is actively required.
- Existing research on field failure feedback presents the flow of different types of information within the process but lacks a management and organisation perspective. It does not emphasize what field information should be captured, analysed and made relevant for use by the design function. Instead it has focused more on the technical aspects of feedback processing.
- There is limited research on holistic feedback process models. The extant models relating to the field data feedback are basic and mainly based on product reliability prediction models and lack operational detail from a management and organisational viewpoint.
- Customer complaint triggers the product field failure analysis and improvement process. To retain existing customers and meet their ever increasing demands, organisations are expected to seek feedback on existing product-in-use performance. This product failure information provides opportunity for designers to learn from their mistakes and integrate the voice of the customer into new product design and development in order to make quality and reliability improvements. Quality engineers also require the field failure data in identifying failure trends such as the type, quantity, frequency and causes of failure. This information is used for setting quality improvement targets, conducting product reliability prognosis and failure analysis whereby corrective actions are

assigned to either reduce the consequences of failure or eliminate the failure from reoccurring.

- Existing research on the field feedback processes is mainly from the consumer electronics industry and particularly emphasised the need for a fast and effective feedback information loop to the product development process (Petkova *et al.*, 2005; Molenaar *et al.*, 2002; Sander *et al.*, 1999; Lu *et al.*, 1999) Molenaar *et al.*, 2002 presented a structure of the feedback process in terms of information flows which illustrated the activities in the feedback process as a function of drivers such as cost, time and quality. Petkova *et al.*, (2005) presented guidelines for building field feedback information flows facilitating decision taking during product development. Sander and Brombacher (1999) developed the maturity index of reliability (MIR) model to assess the quality and reliability oriented information flows. Through the review of the literature it was recognised that other researchers have identified the importance of the field the feedback process for making product quality and reliability improvements, but to date there is little research focus on what constitutes the stages of the feedback process operations. However, it has examined product field feedback from service-to-design function from a fragmented view focusing on certain parts of the process.
- There is little research to understand how feedback from service-to-design should be managed to support product improvement. Findings from the literature suggested a number of key antecedents to consider for an effective field failure feedback process into the product development process. For example, Kumar and Harms (2004) asserted that simplicity is the key to analysing and understanding a process and by identifying commonalities within the process operations, standardisation can be achieved. The structure of the product field feedback should present different functional discipline perspectives and experiences.
- Knowing the root cause of a failed product, via using techniques such as FMEA, is important in understanding the problem at hand and in drawing reliable conclusions on making improvement to the product. Brombacher (2000) asserted that how field feedback is captured, processed, analysed and deployed is relevant to an organisation, in improving product quality and reliability. Some research has looked at improving the field data collection process in particular the speed of analysis, the metrics used and the utilisation of the field failure information (Petkova *et al.*, 2004; Molenaar *et al.*, 2002; Petkova *et al.*, 2006; Sander and Brombacher, 1999). Literature suggested that the speed of field feedback process must be fast enough to improve current products and prevent reoccurrence in future products generations.

7.1.2 Research Objective 2

To empirically inform theoretical findings and develop a conceptual framework for the process of field failure feedback process from service-to-design.

An in-depth exploratory single case study approach was conducted within the sponsoring company who is a heating systems manufacturer. To this end, an empirical investigation was conducted at the sponsor company to understand the existing feedback process from service-to-design, identify limitations of the existing process including the identification of hindrances to effective management of feedback process from service-to-design. Evidence used in the study came from a broad range of sources and data types. A rich set of qualitative and quantitative data was gathered through semi-structured interviews and questionnaires. The data collected was recorded, transcribed and content analysed. Through this analysis, key themes were identified and an understanding of the feedback process established. The main themes from the analysis are:

- The feedback process from service-to-design is useful for making quality reliability improvements in product development projects.
- The speed of the feedback information on product failures in the field from service-to-design is often slow. It takes up to six months before information about field data is usually available. Thus, it does not contribute much to quality improvement in the current product. Problems in the field are sometimes not immediately detected until there is a high frequency of failures.
- The collected field data are mostly incomplete and not root-cause related. Therefore, data collected by service engineers from the field is often not usable by design engineers in making product quality and reliability improvements. Hence, further investigation is required to establish an understanding of why a component or product failed.
- There is no direct communication between service engineers that collect the field information and the design engineers that utilise the field information.
- The tools used for field data capture are not capable of capturing vital information and in a standardised manner for product improvement.
- The feedback process also lacks a significant degree of formalisation within the procedures of the organisation.
- The feedback process is often uni-directional i.e. service-to-design and the design function rarely fed back into the service function.
- Service engineers lacked a detailed understanding on the subsequent use of the information they collated in the field and the implications of poor data when making changes to product designs to improve quality or reliability performance.

Based on the highlighted findings from the empirical study it is evident that the occurrence of failures in products in use is inevitable. The challenge for manufacturing organizations is to have the capability to identify these failures, disseminate the failure information to the appropriate stakeholders as quickly as possible in order to analyse the failure modes and assign corrective measures that prevent failures from reoccurring in new product generations. It was concluded that changes are required to improve the existing service-to-design feedback process operations; making them more effective for use by the functional product development and design improvement teams.

7.1.3 Research Objective 3

To further validate the framework via case studies.

To achieve this objective a validation exercise for the conceptual framework (of service-to-design field feedback process) was conducted with service, quality and design experts within two industrial case companies. The first validation exercise was conducted with the sponsoring company (Case company A) of this research whilst the second was conducted with a manufacturing company from within the wider vacuum systems industrial sector (Case company B). The findings from the industrial validation were supported with literature as discussed in chapter 6.

The first validation exercise was carried out with the aim of assessing the applicability, usability and implication for practise if the proposed framework was to be implemented within the organisation. The approach was taken in both companies and involved process experts from the service and product development functions in the context of case study research, interviews were conducted with the experts using open ended questions to fully articulate opinions and suggestions for framework refinement. The finding revealed that the case company A was also experiencing similar problems to case company B, with regards to their existing feedback process. This highlighted that despite the fact that the empirical findings were based on an in-depth analysis of a single case company, some of the findings may have generic traits relevant to the wider industrial sector. This is also established in some of the findings from the literature on research conducted in the electronic industry about the field failure feedback process.

All the participants of the validation exercise agreed that the proposed antecedents of an effective service-to-design feedback process framework are useful, applicable and usable in the product development process. However, the participants generally emphasised that the framework must consider awareness and training requirements during implementation.

7.2 Contribution to knowledge

Miller (1991) stated that the purpose of applied research is 'to create knowledge that can be used to solve pressing social and organisational problems'.

Easterby-Smith *et al.*, (2002) meanwhile asserted that applied research should result in a solution to a specific problem identified by a client.

The purpose of this section describes the contribution to the existing body of knowledge and theory. This research has made contributions to knowledge, not only to research published in the literature but also to addressing problems in industry.

The contribution to knowledge provided by this research is a conceptual framework to guide practitioners through a holistic approach to collating and processing the feedback of product-in-use failures from service-to-design functions. This is embodied in a structured and integrated process operation that facilitates decision making, for the purpose of improving product development capability. The resulting conceptual framework makes explicit the antecedents that constitute a set of conditions for the effective management of product field failures feedback from service-to-design as follows:

- Nature of the feedback process: This antecedent describes the characteristics of an effective feedback process. The feedback process is an iterative process of learning from failures and making improvements and therefore the process must be dynamic, multi-directional, formalised, show transparency in its path dependencies and presents outcomes in terms of its knowledge states.
- Feedback process operations: This antecedent describes the main stages of the feedback process and espouses the need to perform them in a holistic manner to enhance its overall effectiveness. It presents the feedback process as a set of structured operations that comprise three stages of activity namely; **capture**, **sense making** and **utilisation**. The outcome of each stage serves as input to the subsequent stage and therefore the quality of the outcomes is very important. For example, for quality failure data to be captured in the field, the key process stakeholders (service quality and design engineers) must co-design the template used by service engineers in recording data in the field. This will help to ensure that the requirements of all data users are incorporated in the failure recording system. It also suggested that the classification scheme used for the failure descriptions (and identification) should also be standardised to enable a common understanding of faults and finally that the field data collated should also include context-specific information, to complement the product-specific counterpart to assist in developing understanding of root causes of failures.

The second stage of activities in the process operation is 'sense making' of the raw field data. This research suggests that a *meta analysis* of the various failure analyses should be conducted and co-translated and co-interpreted to generate meaningful and relevant insights that can be used for product development improvements. This establishes a more unified understanding of field problems amongst the design, service and quality functions and therefore raises their competency levels for identifying root

causes of failures and proposing corrective actions to resolve such problems. The final stage of the feedback process operation is the 'utilisation' of existing products-in-use failures. This knowledge is utilised by design, service and quality engineers collectively in decision making processes for product quality and reliability improvements for new and existing product generations.

- **Integrating mechanisms:** This antecedent suggests that an effective service-to-design feedback process requires integrating mechanisms such as communication, team effort and a centralised database repository that facilitates knowledge sharing, information dissemination and the efficient execution of the field feedback process. For example, the effective management and organisation of service-to-design feedback process requires an efficient formal and informal communication method. This would strengthen an organisation's capability to define information movement and enhance collaboration between the functional teams. Furthermore, using appropriate communication tools and methods would expedite the feedback process and maximise management efficiencies.

The feedback process cuts across different functional teams, and the collaboration and interdisciplinary immersion of these functional teams would provide a wealth of knowledge in understanding and managing the process and improving its effectiveness.

- **Governance:** This antecedent suggests how the feedback process operations should be governed. Process governance is essential for monitoring and controlling its operations and maintains consistent practise to establish directions for future improvement. Governing the feedback process involves defining quality controls, roles and responsibilities of the process stakeholders, measuring the performance of the process in order to improve on its effectiveness, enhancing the process capabilities to ensure that it is meeting the intended purpose. By establishing a field feedback process governance structure, an organisation would be able to administer its entire process through policies, standards and guidelines to optimise and manage successfully.

The proposed antecedents would enable an organisation to improve its process capabilities in managing the flow of information from service-to-design for improving the quality and reliability of their products. The continuous improvement of the feedback process through the evaluation of its performance and how well it is meeting the needs of its users would enable an organisation to build competencies in data capture, sense making and utilisation in the feedback process for product improvement.

7.2.1 Contribution to theory

The theoretical contribution to knowledge is primary to this research as the framework for the antecedents of an effective service-to-design feedback

process has not be developed and approached from a holistic perspective. Existing research concerning field failure feedback process has examined it from a fragmented viewpoint, focusing on particular aspect of the process such as speed of information flow (Boersma,2001), the analysis of the failure data, the structure of the feedback process in terms of information flow (Boersma *et al.*,2005, Sander and Brombacher,2000, Petkova *et al.*,2005, Fundin and Bergman ,2003) and not enough research focused on how product failure data is transferred from service-to-design for use in making product improvement, how the actual feedback process should be managed and what should constitute an effective feedback process. Through the analysis of the findings from the literature and empirical investigation, this research extends existing theory by proposing a framework of antecedents an organisation should follow when executing service-to-design feedback process. The proposed antecedents of an effective service-to-design feedback process provides an ample description of guiding principles for management and organisational considerations for each of the main activities involved in the feedback process.

The research suggested that service-to-design feedback process should be considered has a holistic process consisting of three main process operations which are dependent on each other's inputs in order to perform their individual roles, as well as function as a complete process. This has led to the definition of service-to-design field feedback process as *"an integrated and holistic approach for disseminating data about product-in-use failure that supports a cohesive interpretation of information, whereby outcome of failure data analysis is transformed into knowledge for use in making product improvement"*. This definition highlights some key features for managing service-to-design feedback process which have not being identified in existing research and therefore makes it a novel contribution to knowledge.

7.2.2 Contribution to practise

The proposed antecedents are expected to:

- Refocus the organisations attention on quality by ensuring that quality is considered a paramount factor throughout the feedback process operations especially at the capture stage because the quality of data captured has an adverse effect on subsequent activities in the process.
- Establish a formal structure for transferring product-in-use failure feedback from service-to-design.
- Make service engineers work easier, through standardising terminologies for failure modes, and the reclassification of options in the failure reporting system, which would allow service engineers to give an accurate description of event encountered in the field.
- Help practitioners to understand preceding factors that could enable the effective management of service-to-design product failure feedback process.

- Motivate service engineers into capturing quality data that are more relevant for use, through their better understanding of the data required from the field and the subsequent use of such data, in achieving the end-goal of the feedback process.
- Supports learning through cross functional collaboration such as interdisciplinary immersion where functional teams can learn from each other, and as result;
- Support practitioners in establishing ownership of the feedback process, and setting performance measures to ensure that the feedback process efficiency and effectiveness is continuously improved to make it relevant for use.
- Integrate the functional teams, process and systems through formal and informal communication methods thus optimising the feedback process effectiveness.
- Enable collective understanding of the feedback process procedures through sense making, which would allow the functional teams to be more cohesive when performing their duties.

7.3 Limitations of the research

The research has achieved its set objectives by developing a conceptual framework of the antecedents of effective service-to-design field feedback process. Despite this, there are still some limitations to the research. This section presents the apparent limitations of this research. Though the limitations of this research study are acknowledged, they do not detract from the significance of the findings.

The development of the theory and proposed framework was based on a single case; therefore further research could be taken to involve multiple case studies in the empirical investigation that led to the findings and derivation of the developed framework. A wider number of manufacturing companies from different industrial sectors that have a product development process and service offerings could have been used for the exploratory study and the validation of the theory and developed framework.

The research was an exploratory study using both a qualitative and quantitative approach due to the dearth in the existing body of knowledge relating to the research subject. By implementing both research approaches it allowed for the collection of explorative data in a valid and clear method for the development of concepts and theory. The researcher felt that by adopting both approaches it would be more beneficial to the research study as it allowed for the development of theory based on rich understanding of the subject domain. The chosen research methodology has been justified in chapter 3. Future research could include the collection of more measurable data; such as the questionnaire survey data to enhance the validity of the findings.

7.4 Recommendations for future work

This research has provided novel understanding and insights into how field failure data are fed back from service into design for making product improvement. It has also highlighted problems with the quality and content of field data and the overall organisation and management of the feedback process. This led to the development of a conceptual framework of antecedents for an effective feedback process from service-to-design to support product improvement. This section makes some recommendations for further work that have emerged out of this research study and also to support limitations identified in previous section.

Findings from the research indicated a lack of integration between field data and FMEA process. Therefore further research could be conducted on how to integrate both aspects, by identifying the methods and steps that can be taken for seamless integration.

Feedback of field failures was identified as a learning opportunity for the organisation; however, the learning aspect was not fully explored in the research. Further research can investigate different methods of learning and their implications to the product innovation process.

The proposed framework instigates changes to the existing working practise. People are often not receptive to change; future research could investigate how to manage the transition of changing from the existing practise to the new process.

The research recognized problems with the classification of failure modes description. This problem can be investigated further to develop a standardised failure description classification scheme.

The research identified that root causes of failures are very important for product quality improvement and currently not recorded by field service engineers. This problem can be investigated further to examine methods that could guide service engineers in identifying failure root causes and subsequently develop a troubleshooting guide to aid the process.

To enhance the validity of the research, further investigations can be conducted to test the applicability and impact assessment of the proposed framework and research findings in a real life product development project. The empirical result can be replicated using the same scope or using a reduced or more refined scope within different industrial context.

7.5 Concluding remark

In conclusion, this research study has presented its research findings and contributions and achieved its aim and set objectives of developing a conceptual product field failures feedback process framework. The review of literature identified a number of research gaps, which suggested the need for an effective field failure feedback process from service-to-design. The identification of the limitations of the research led to recommendation for future work. A

significant and novel contribution to the body of knowledge was also established.

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APPENDIX I: COMPANY LETTER & INTERVIEW QUESTIONS

PhD Research: Design for Service: Improving Feedback Loop from service-to-design using FMEA technique to enable improved product quality and reliability

Researcher:

Dupe Ajayi, Affiliation: Cranfield University, UK

Supervisors:

Dr Palie Smart: Affiliation: Cranfield University, UK

Dear Sir,

INDUSTRIAL EXPLORATORY STUDY: INTERVIEW QUESTIONS

I am a PhD student working on the above research topic. I would like to solicit your support and time in participating in a 1 hour interview session. My research focus is on FMEA process improvement, while enhancing the feedback loop from service into design. The main objective of this interview is to collect data on the following:

- current failure feedback process,
- identify barriers and enablers for improving the failure feedback process
- impact of service failure feedback on design and
- develop a feedback process map.

For the purpose of clarity, you may prefer to take a typical fault and use as an example to explain the process. The outcome of the interview will be used to create a process diagram of the different stages in the feedback loop. The questions I would like to ask can be found overleaf. If you have any company documentation that would be useful and can be taken away, may you kindly bring it with you to the interview.

With your prior permission I shall seek to record the interview. I can assure you of absolute **confidentiality** and **anonymity** in dealing with the information you may provide. I also promise to share the results/findings of the research with your company by submitting a copy to you on completion of the research project.

Please, do not hesitate to ask for further clarification where any question(s) is/are not clear enough. I look forward to your early response and proposed dates of your availability during the period of mid January – early February 2007 or at your earliest convenient date. Please email them to me at the address below.

Yours Sincerely,

Dupe Ajayi

Doctoral Research Student

Cranfield University

Tel: 01234 750 111 ext 5641, email m.o.ajayi@cranfield.ac.uk

Interview Questions for Design Engineers

Dear Design Engineer/Research Participant,

The interview session would be an informal process. The information provided will be treated as strictly **confidential** and **anonymity**. Where possible please use real examples of events to answer questions. I will be seeking to have a conversation with you on the following key topics:

Introduction

Please tell me about your role at vaillant.

General Questions

1. Can you please describe the product design process?
2. How does the FMEA process impact on design?
3. In your opinion how effective is the FMEA process?
4. What are the challenges of performing an FMEA?
5. How can the FMEA process be improved to have better impact on design?
6. How user friendly is the fault data?
7. In your opinion, how can the field failure data help product design?
8. In your opinion how can you propose to improve the feedback loop between service and design?
9. How is the field data currently used in the fmea process? (How would you improve this?)
10. Please comment at the levels of integration between design and service.

Feedback Process (FMEA)

- How is the failure data fed back into the product design process?
- What hinders the feedback process?
- What optimises the feedback process?
- How can the current feedback from service-to-design be improved?
- Are there any success stories with the feedback process?
- What other data can be collected by service engineer that would be useful for design improvements?

Field failure data for product design

- When in the design process is field failure data required?
- How do you prioritise some faults over others?
- How is the failure data analysed?
- Is the right field failure data available at the right time? If not why?
- What are the biggest challenges of using the field failure data?

Mop-Mis database

- What is (are) the current uses of the database?
- Who uses the database and for what purpose?
- What are the limitations of the database?
- How can it be improved?
- Can you please take me through an example, when the feedback process has been particularly effective?

PHD Research: Design for Service: Improving Feedback Loop from service-to-design using FMEA technique to enable improved product quality and reliability

Researcher:

Dupe Ajayi, Affiliation: Cranfield University, UK

Supervisors:

Dr Palie Smart: Affiliation: Cranfield University, UK

Dear Sir,

INDUSTRIAL EXPLORATORY STUDY: INTERVIEW QUESTIONS

I am a Phd student working on the above research topic. I wish to solicit your support and time in participating in an interview session. My research focus is about improving FMEA process by improving the feedback loop from service into design. The objective of this interview to collect data on the current fault reporting process, current barriers and enablers to improving the fault reporting and feedback process from service-to-design. You can take a typical fault and use as an example to explain the process.

The outcome of the interview will be used to create a process diagram of the different stages in the feedback loop. The questions I would like to ask you are on the next page. If you have any company information that would be useful and can be taken away, please bring it with you to the interview.

With your prior permission I will seek to record the interview. I can assure you of absolute **confidentiality** and **anonymity** in dealing with the information you may provide. I also promise to share the results/findings of the research with your company by submitting a copy to you on completion of the research.

I hope you will find the questions easy to follow. Do not hesitate to ask for clarification where any question(s) is/are not clear enough. Please email suitable dates when you are willing to be interviewed for approximately 1hour.

Yours Sincerely,

Dupe Ajayi

Interview Questions for Service Engineers

Dear service Engineer/Research participant,

The interview session would be an informal interview. The information provided will be treated as strictly confidential and anonymity. Where possible please use real examples of events to answer questions. I will be having a conversation on with you on the following key topics:

Fault reporting process

- What is the existing protocol for collecting field failure data?
- What is the most critical aspect of the fault reporting process?
- What hinders the existing process?
- How can the fault reporting process be improved?
- In your opinion how would you radically change the role of service engineers to improve fault reporting?
- Does your role as a service engineer go beyond reporting process? For example do you get involved in the analyses of the data?

Fault reporting sheet

- Who was involved in designing the sheet?
- What is included in the sheet? (Please bring a copy to our meeting.)
- Is the sheet capable of capturing everything relating to the fault?
- How can the sheet be improved?
- Is there other information (non product information) that could be useful if collected?

Mop-Mis database

- What is (are) the current uses of the database?
- Who uses the database and for what purpose?
- Who is responsible for the analysis of the mop-mis data?
- What are the limitations of the database?

- How can it be improved?
- Can you please take me through an example, when the feedback process has been effective?
- How is the failure data feedback into the product design process?
- What hinders the feedback process?
- How long does it take to get a feedback on a product from when its launched?
- What optimises the feedback process?
- How can the current feedback from service-to-design be improved?

Field failure data

- When in the design process is field failure data required?
- What kind of data do designers require from the field?
- What type of data do you currently obtain from the field?
- How is field failure data used?
- How do prioritise some faults over others?
- How is the failure data analysed?
- In your opinion do you think service is an essential element of the improvement process?

APPENDIX II: EXAMPLE OF INTERVIEW TRANSCRIPT

Interview Questions for Design Engineers (Transcript 3, Respondent C)

Dear Design Engineer/Research Participant,

The interview session would be an informal process. The information provided will be treated as strictly **confidential** and **anonymity**. Where possible please use real examples of events to answer questions. I will be seeking to have a conversation with you on the following key topics:

Introduction

Please tell me about your role at vaillant.

Project manager in r&d dept, involved in innovation project, pre-development is the key aim. Currently working on electronic gas air systems.

General Questions

Can you please describe the product design process?

Working along with the ip, which has different phases beginning with the strategy phase. Product design process. - First make a study of the space you have for the design on the cad system. Develop hardware prototype, rapid prototyping, sheet metal prototype, to valid the design, to assembly test with the prototype. If this is validated you finish the design freeze. Then you are obliged to spend the money for the tools. Release the order. Depending on the time schedule or tools you have it may take 3 to 5 months to make order. 04:00

How does the FMEA process impact on design?

There are different fmea, first is the product fmea which translates customer needs into product requirements or specification.

System fmea where we consider what in the system may fail without knowing the design in details. Just about thinking about functions, functional relationship btw different groups such as thermal, hydraulics, combustion, electronics. If that is clear then we go to the design fmea , where we have ready design parts, so we look at tolerances, easy to assemble etc

Process fmea is on how to produce the part and how to assemble.

The main impact on design is the system FMEA phase and the design phase.

In your opinion how effective is the FMEA process?

Fmea is a powerful tool; it needs to be conducted in a strict manner. At the end of the day, the failures that occur are those you forgot to look at during the fmea session. The normal question is why wasn't this recognised in the fmea? It is a good tool but it is not an automatic failure prevention solution that if you use this tool, you will never make failures. We use existing fmea when we are dealing with similar product for example if we are talking about modification on existing product. But I think the experience of the people is the most important. What you give in to the process is what you will get out of it. Because you done an fmea does not mean failure will not occur.

How can the FMEA process be improved to have better impact on design?

One thing to imagine is to make the experience more suitable, it is easy to say and hard to realise. We very often talk about knowledge databases, but until we have the experience its very hard to handle not the database because its just a a piece of software, but we need experince to be able to handle all the information in it and make it very clear for others to understand.I think this is the real issue. My experience with knowledge databases is there are lots of data in, if you look for something you will find something for example like in google. But you have to understand it and at the end of the day you look for the author of the data and contact the author for further explanation to the data. if the author is still available then you are lucky, if not, it is not so effective. So that is the problem I have with such knowledge databases. In principle I think we have to store our experiences, but the way to make them transparent for the following project is a challenge. You very often see if we look into the past or discuss with other people who have in the business for long, they look at the design or a function and say there might be in problem, why because in 1990 we had a similar problem. Very often failures occur again and again.

Suggestion: to have an historic database of previous failures and solutions and I think it is very important to visualise it, not only to have text also to visualise it. A picture normally tells a lot more than a text. For example if there is a problem with the sealing, just to describe the problem and the photo of the broken sealing, but more or less what are the causes, but to have some sort of visualisation depending on the type of problem. Latest In the designer fmea we have prototypes of the parts, so that is one of the rules if you are doing a design fmea, put a prototype or a sample on the table, so that everyone knows what we are talking about.

How user friendly is the fault data?

We have intranet access to access the data, and it is quite easy for me, I think, if you have done it once or time, it is quite easy to access. To evaluate the data, find the real causes for the failure is more adder on one side if you have a very detailed failure code, service engineer sometimes does not really which field to put a text. You have very small amount of clusters, you might not see where the real failure is because its sort of messed up. If you do it highly integrated, so only a hand full of possibilities to set a text the other way round, you will again don't see the real failure because he has to set text on one item and I wonder if it really represents the failures he was faced with. If it is too detailed it becomes messed up if it is too integrated is see nothing so it is really hard to find. if you big problems with high failure rate in the field, you will see because it is very clear. If you want to improve quality for our 1 digit per target you have to go very much into detail. it is difficult to identify the root cause of the failure from the failure data. you have a highlight "problem with high volume" it is quite easy and you get a very fast overview about the situation, if you have to go very deep into single failures to improve the quality, its very hard to find. In some cases we call the service engineer and ask him "so what was the problem".

In your opinion, how can the field failure data help product design?

This again has to do with experiences. If you didn't manage to get the filed failiure data failures during the design phase and there are still some products in the field. The same failure should not occur twice. What we try to do is to have a close link between the failure data and field failure data and new project. For example one of the task of marko and his colleague is to support the project team. "Problems that are identified in the field are analysed and resolved. The solutions to these problems are then implemented in new project".

In your opinion how can you propose to improve the feedback loop between service and design?

We have the cpi, who are responsible for quality improvement, they collect field data and of course they solve problems. They collect all the experience out of the actual series production. All failure which occurred in the field, they have knowledge about that. Normally if you kick off a new project, you should have access to the cpi. For example if a designer has to develop a new condensing boiler, he would need to contact the cpi team, to get information on the actual failures in the field, so that they don't do the failure twice. But the cpi team located here in remschied and in different plant. They are not in the same area. The feedback loop from the service engineer should be improved. Few years ago I was project manager for cpi, and in those days we organised some round table discussion in the different service areas for example in germany, netherlands and verara to have direct contact with service engineer, to discuss, not only via failure data which is inputed into the computer everyday but just face to face. It methods is useful because you get a lot of information between the

rules. Information that are not normally captured in the field data. More contact with the service technician. What we still do in some cases when we have a new product in the market we have a hotline, so its just a mobile phone which the R&D team which is responsible for this product release can be reached by the service engineer. It not for the customer or for the installers, it is just for the service technicians, so for example we have one product which is highly innovative and has been in the market since 3yrs, honestly we had a lot of problem at the beginning, we've had this hotline since 3yrs ago and we have direct contact to the service technicians.

The information gathered from the hotline is not entered in the mop-mis directly, if the service engineer has a complaint with such boiler he uses the hotline, in parallel he still needs to put the details of the problem and what he has done in his computer, as normal. The purpose of the hotline is to get more information on special solutions to a problem, the hotline is just additional to what the service technician normally does to repair a fault.

How is the field data currently used in the fmea process? (How would you improve this?)

My feeling is that the highlights"very well known problems" are recognised very well and implemented into the next fmea, a lot of small things might be left out. There is no real systematic at the moment, very well known problems are used in the fmea no one will forget to put the well known failures into fmea but the small problem can easily be forgotten and not included in the fmea.

How can it be improved, so that the fmea covers all areas of failures identified in the field?

I think the practical way is to have a link to the cpi team. The real failure mechanism, you cannot read out of the field data. more analysis is require to identify the root cause. That is not deliverable by such a database alone. The database only gives high level information, may some hints to one of the other direction but to put it one to one or take one high level problem and put it into fmea and say "that is the pont we don't have to forget, not quite easily.

Please comment at the levels of integration between design and service.

Service is involved very early in the innovation process. There are some customer reviews at certain milestones, very early in the beginning, long before design freeze, the service organisation is invited to have look at the product, to do some assembling, to do some maintenance etc. they are given a given a prototype of the product, but I don't think is sufficient service engineer have to carry is tools etc, so they cannot help with the digital prototype in the CAD system.

There are several review, the very first one is with the digital prototype, that's not so effective, the next one is when you have a prototype not with the series tools but just with the prototyping machine that is sufficient to get the first feedback. And that is what we normally do. "Feedback from hardware prototype"

Does a designer get involved with training of service technicians?

Normally before market release service engineers gets trained on new product. The R&D team or the innovation team is invited to the training. 1 or 2 guys from this team attend the training to answer questions to get a feedback directly. That very often depends on who is organisation what. It is not automatism. If the service trainer thinks it is ok to get some support from R&D during this training. 30:00.

Do you think it is beneficial for service engineer during training to have someone from r&d to be present to answer questions etc that may help to capture relevant field data or identify the root cause of a problem.

when we have the very first training on a new product we normally don't know failure which would occur afterwards, if we did, we would solve them in advance. So its more or less understanding of the service engineers of the appliance. So that makes its easier if a failure occur.

Feedback Process (FMEA)

- **How is the failure data fed back into the product design process?**

The highlighted failures have a direct feedback into the design process. Feedback is mainly through mop-mis, also production issues, if we have complains in the production line "first pass yield rate" it is a figure which shows at the of the assembly the appliance get tested before delivery to the customer and this figure points out how many appliance pass yield rate without any failure. So if you have an 100 percentage pass yield rate, you did an excellent assembly without any problems or maybe the test was wrong. This is not only related to R&D and design it is also related to suppliers with quality problem or in the shipping audit.

- **What hinders the feedback process?**

If you work on the highlighted failures, then normally you look at the pareto and you can get the rate of the first bar. Very often people are working on other issues, this concerns are not so important, if you have really highlighted the problems and everyone agrees to work on it, there is no doubt about it to work on those concern if you are working on the smaller problems, It is sometimes easy to get the write results to delegate the resources to those task.

Getting the right resources.

- **What optimises the feedback process?**

More direct contact with the service engineers. Round table discussion, other things we have done in the past which I think was not too bad was interaction list, which was not more than excel sheet, where service engineers or their supervisors put their concerns based on their experiences with the customer, what they are faced with, what they are afraid of, what they are angry about, and not what is the highest in the mop-mis data. so they can these concerns into such a list. This list is passed on to the cpi team and they have to put their comments on for example, we know this problem, we have a solution in two months, we are not working on this problem at the moment due to several reasons if someone think it is important we have to set a priority but that is the task of the project leader, this problem is work in progress. These concerns are away from the mop-mis data, it should be information about what the service engineers are faced with in the field. As far as I know we don't have such list at the moment, so we practise it in the past, depending on how many resources is in the cpi, you get more or less.

How can the current feedback from service-to-design be improved?

Same as above

Are there any success stories with the feedback process?

The success story I think is the hotline, which is available after the market launch. If you wait until you evaluate the mop-mis data you have three, four, five months in the future. If you have a direct contact to the service engineer, within the first two weeks, after the market introduction and you have five calls with the same problem, you don't have to wait for mop-mis data increase. This hotline is very powerful if you have a new product, new technology. We have a few failures instead of waiting to get all the data in the mop-mis. It's a quicker feedback instead of waiting for six to nine months for getting all the data from mop-mis.

For example, we had a release software version for a boiler, there was a bug in it, which led to a failure to do with temperature measurement in the water flow and in combination with driving the pump, the heat input was too high the pump rotation was too low which led to over-heating and short down of the boiler and this failure was found within a few days of market release, we did some checks in the lab and found out the failure, we develop a solution and handed to the service engineer. The software is on a printed circuit board, so the old PCB was taken out and the new PCB was given to the service engineer. Technically you can also put the software on the PCB in field, but in practise we changed the PCB with a new one. When we had a solution with the first sample, we could directly send it some of the service engineers.

Field failure data for product design

- **When in the design process is field failure data required?**

- **How is the failure data analysed?**

Using pareto

- **How do you prioritise some faults over others?**

Using the pareto analysis, generated from mop-mis data. mop-mis data mostly give the amount of failure of appliances which are affected. In some cases there is failure for example the boiler does not shut off, so the customer complains that flat is too warm. On the other hand, sometimes you have failure which are not too much but occur permanently or frequently. If you have only one failure in only a few appliance, that failure get only known about via hotline, in some cases service organisation or customer care centre call us and give us some hints, so you cannot read this failure out of the mop-mis normally. Also there is a community on the intranet where service engineers and their supervisor can put some comments on appliance based on their experience in the field. If there is a complain which a lot of people are talking about then we can ask the colleague to carry out further investigation. We have access to these comments.

How often is this community accessed? - Not regularly, sometimes I check to see if there are new comments but not regular.

- **Is the right field failure data available at the right time? If not why?**

The availability of the field data is very good. It depends on the product because if you have a new product with new technology and if you have an hotline, then you will get a quick feedback. Otherwise it takes a little time. Normally if you release a boiler into the market, you don't release the next one till half a year later, there is something to learn from the mop-mis data. You have a chance until you release the next product for me the response time is not too bad. What is the average response time? Depends on the failure, some failure occurs very close to the market release with a high volume, 1 or 2 months e.g 1 mis which means failure occurs 1 months after installation. You have early feedback but if you have a long time failure you have to wait.

Mop-Mis database

- **What is (are) the current uses of the database?**

To prioritise the tasks.

To analyse for example if one appliance is affected more than once, you have the series number in the mop-mis database, so can look if it is the same series number, if you find it 10times if you the customer has had a lot of complaints. You can also see the service engineer dealing with the appliance and call him for further questions. You can also see out of the product range are there special types which are affected

for example only the 20kwatt version or only the liquid gas version. This are all kinds of analysis problems.

- **Who uses the database and for what purpose?**

Cpi for data analysis

Fmea team

Designer

Test lab

- **What are the limitations of the database?**

If the failure code had too many details, you don't find the highlights. Too abstract you don't find the failures. In between this balance there is a limitation. I think just getting the information out of the data.

- **How can it be improved?**

I don't really know. He said that should be my work

- Can you please take me through an example, when the feedback process has been particularly effective?

Do you think the faults can be better classified/? Again if you are too much into details you don't find the highlights and if you are too abstract you don't find the failures. It is hard to say what is the optimum between both variance.

Does the design team make request what data service engineer need to capture. Not specifically the design team, let me say R&D, they have especially the cpi team sometimes they create a kind of questionnaire, for example if you are looking or searching for a failure and have no idea what really is the matter, sometimes we create some questionnaires and hand it out to the service engineer to get some additional information and they direct it back to us. For example the question can include what was the length of the exhaust pipe, questions that are normally not covered in the mop-mis data. This questionnaire is used when R&D is trying to find a route cause of a problem.

APPENDIX III: AN EXAMPLE OF DATA ANALYSIS

The data coding was done on an excel spread sheet. The following her some examples of the data analysis coding.

Codes		Emerging Key Themes and sub-themes	Categories
1 FMEA IOD	Code Definition	FMEA impact on design	
1.1 Predict failure		Predict possible failure	Data Analysis
1.2 Solutions		Generate solution to identified field failure	Data Analysis
1.3 Prevention		Prevent failures from occurring	Data Analysis
1.4 Emphasise testing		Encourage testing of components before use in design	Data Analysis
1.5 Impact Size		High/Big Impact	Data Analysis
1.6 Learning		Enable development team to learning from past failures	Data Analysis
1.7 Innovation		Generate new ideas or new design	Data Analysis
1.8 Team Experience		Depends on experience of team	Data Analysis
1.9 Customers need analysis		Translate customers need into product requirement/specification	Data Analysis
1.10 Risk		Consider risk from system point of view	Data Analysis
1.11 Implementation		Implement failure solution in new design	Data Analysis
1.12 Quality decisions		It helps to make quality decisions on product design	Data Analysis
2 FMEA effectiveness		Effectiveness of FMEA	
2.1 Level	The levels of effectiveness. E.g good, powerful	Powerful tool	Data Analysis
2.2 Role		It identifies failure modes	Data Analysis
2.3 Quality of input		Outputs depends on inputs to the process	Data Analysis
2.4 Use		Useful to use as action list	Data Analysis

2.5 Discussion Platform		Platform to discuss product functionality	Data Analysis
2.6 Specification		Help to specify new product	Data Analysis
2.7 Optimisation		Optimise some processes	Data Analysis
2.8 Risk		Lowers risk of integrating failures into new design	Data Analysis
2.9 Prevention		Prevent failure from re-occurring	Data Analysis
2.10 Quality Improvement		Improves product quality & reliability	Data Analysis
2.11 Key Task		Major task in the product development process	Data Analysis
2.12 Rating of effectiveness		Very effective	Data Analysis
2.13 Compulsory		It is compulsory for milestones	Data Analysis
2.14 Monitoring		useful to track & trace activities at suppliers	Data Analysis
3 Effectiveness criteria	Code Definition	Criteria for effective FMEA	
3.1 Creative thinking		Creativity to identify failure modes	Characteristics
3.2 Knowledge		Knowledge of the product/process in question	Characteristics
3.3 Team composition		Cross-Functional team	Characteristics
3.4 Experience		Past experience of people on similar product	Characteristics
3.5 Structure		Must be conducted in a strict manner (structured)	Characteristics
3.6 Risk		Team must be capable of thinking in terms of risks	Characteristics
3.7 Question		Asking the right questions	Characteristics
3.8 Understanding		Good understanding of the tool	Characteristics
3.9 Creative		Ability to think outside the box	Characteristics
3.10 Systems environment		Able to think in terms of operating systems	Characteristics
3.11 Skilled resources		It is important you have the right people involved	Characteristics
3.12 Tacit Knowledge		Information in FMEA is what people have in their head	Characteristics

3.13 Specialist		Need a specialist to combine FMEA	Characteristics
3.14 Effort		What you give into the process is what you will get out of it	Characteristics
3.15 Quality Team		FMEA is only as good as the team	Characteristics
4. Improvement factors		Suggestion for FMEA improvement	
4.1 Resource Availability		Availability of cross-function experience	Resources
4.2 People Understanding		Make people understand the importance of FMEA	Know-how
4.3 Knowledge database		Develop FMEA Standard database	Database
4.4 Ownership		Need experience to be able to handle all information in the FMEA database	Know-how

APPENDIX IV: SURVEY COMPANY LETTER & QUESTIONNAIRE

Industrial Survey on Improving Product Innovation for Service Engineers

Dear Sir/Madam,

INDUSTRIAL SURVEY ON IMPROVING PRODUCT INNOVATION: QUESTIONNAIRE FOR SERVICE ENGINEERS

The aim of this questionnaire is to investigate the field failure feedback process to design or R&D in the context of Failure Modes and Effects Analysis (FMEA). In particular I am interested in the role and activities of service engineers in this process. This study forms part of my doctoral studies, which has been kindly sponsored by Valiant at Cranfield University, UK Ultimately, I hope to identify and locate the need for improvements to Valiant's current processes for the purposes of product innovation.

I can assure you of **absolute confidentiality and anonymity** in dealing with the information you may provide in this survey. I also promise to share the results of the research with Valiant on completion.

I hope you will find the questionnaire easy to follow. Please do not hesitate to ask for clarification where questions appear unclear.

I would like to take this opportunity to thank you for your kind cooperation.

Yours faithfully,

Dupe Ajayi

Name (Optional): _____

Department: _____
(Optional): _____

Position

Please read the statements below and **circle the most appropriate response**. It is advised that you do not spend too much time on each statement. This survey should take approximately 15 minutes.

General Questions

1. I have a good level of understanding on Failure Mode and Effect Analysis (FMEA) and its application in product development

Strongly agree Agree Neutral Disagree Strongly disagree

2. Root causes of product failures are identified and recorded on the field worksheet (mop-mis)

Strongly agree Agree Neutral Disagree Strongly disagree

3. There is a need to improve the way failures are classified, so they better represent the actual failures in the field

Strongly agree Agree Neutral Disagree Strongly disagree

4. In addition to the textual method, product field failure data is captured in other useful ways (e.g. video, audio, pictures)

Strongly agree Agree Neutral Disagree Strongly disagree

5. The product field failure data reporting worksheet (mop-mis) captures all the necessary information about product failure for future corrective action

Strongly agree Agree Neutral Disagree Strongly disagree

6. Service engineers are aware that the product field failure data is captured for the purposes of future product improvement

Strongly agree Agree Neutral Disagree Strongly disagree

7. Design engineers use the field failure data captured by service engineers for the purpose of product improvement

Strongly agree Agree Neutral Disagree Strongly disagree

8. The feedback process of field failure data to design department is well understood by service engineers

Strongly agree Agree Neutral Disagree Strongly disagree

9. Service engineers are involved in the product design process

Strongly agree Agree Neutral Disagree Strongly disagree

10. The product field failure data allows for subsequent analysis of reoccurring problems across product families

Strongly agree Agree Neutral Disagree Strongly disagree

11. The mop-mis database is a useful tool in the feedback process from service department to design or R&D

Strongly agree Agree Neutral Disagree Strongly disagree

12. Service engineers are involved in analysing field failure data

Strongly agree Agree Neutral Disagree Strongly disagree

13. The feedback process from service department to product design is clearly defined and measurable (for e.g. in guidelines, manuals, process flow diagrams exist)

Strongly agree Agree Neutral Disagree Strongly disagree

14. The quality of feedback from the service department to design or R&D is regularly assessed

Strongly agree Agree Neutral Disagree Strongly disagree

15. The product field failure data is a useful input to System level Failure Mode and Effect Analysis

Strongly agree Agree Neutral Disagree Strongly disagree

16. Changes are necessary in the product field failure feedback process from service-to-design or R&D for the purpose of product improvement

Strongly agree Agree Neutral Disagree Strongly disagree

17. Classification of failure options given in the field worksheet (mop-mis) is adequate for characterising product failures in the field

Strongly agree Agree Neutral Disagree Strongly disagree

18. Failure data recorded at end of each service callout give a true reflection of the problems in the field

Strongly agree Agree Neutral Disagree Strongly disagree

19. Identify three ways the options given by the field failure data recording system(mop-mis) can be improved

20. Identify three ways to improve product field failure feedback to R&D and Design process

THANK YOU

If you would like to take part in 20mins telephone or face to face interview please include your contact details.

Dear Sir/Madam,

INDUSTRIAL SURVEY ON IMPROVING PRODUCT INNOVATION:
QUESTIONNAIRE FOR DESIGN ENGINEERS

The aim of this questionnaire is investigate the application of product Failure Modes and Effects Analysis (FMEA). In particular, I am interested in exploring the product field failure data feedback process, and how it can improve product quality and reliability. Ultimately, I hope to identify and locate the need for improvements to Valiant's current processes for the purposes of product innovation.

This study forms part of my doctoral studies, which has been kindly sponsored by Valiant at Cranfield University, UK.

I assure you of **absolute confidentiality and anonymity** in dealing with the information you may provide in this survey. I also promise to share the results of the research with Valiant on completion.

I hope you will find the questionnaire easy to follow. Please do not hesitate to ask for clarification where questions appear unclear.

I would like to take this opportunity to thank you for your kind cooperation.

Yours faithfully,

Dupe Ajay

Name (Optional):

Department:

Position (Optional):

Please read the statements below and **circle the most appropriate response**. It is advised that you do not spend too much time on each statement. This survey should take approximately 15 minutes.

1. Product field failure data captured by service engineers is a useful input to product FMEA

Strongly agree Agree Neutral Disagree Strongly disagree

2. Product field failure data captured by service engineers is actively used in conducting product FMEA

Strongly agree Agree Neutral Disagree Strongly disagree

3. The design department specifies what product field failure data should be collected by service engineers for the purpose of product FMEA

Strongly agree Agree Neutral Disagree Strongly disagree

4. Design engineers get involved in the analysis of the product field failure data

Strongly agree Agree Neutral Disagree Strongly disagree

5. The existing protocol for capturing product field failure data is conducive for product Failure Modes and Effects Analysis (FMEA)

Strongly agree Agree Neutral Disagree Strongly disagree

6. In addition to the textual method, product field failure data can be captured in other useful ways (e.g. video, audio)

Strongly agree Agree Neutral Disagree Strongly disagree

7. Product field failure records capture contextual information about product failure

Strongly agree Agree Neutral Disagree Strongly disagree

8. Design engineers are aware that the product field failure data captured is done for the purposes of product FMEA

Strongly agree Agree Neutral Disagree Strongly disagree

9. Product failure data gathered from the field is of sufficient detail for the purposes of product FMEA

Strongly agree Agree Neutral Disagree Strongly disagree

10. Design engineers are actively involved in service / product in use activities

Strongly agree Agree Neutral Disagree Strongly disagree

11. Service engineers are actively involved in the product design process

Strongly agree Agree Neutral Disagree Strongly disagree

12. Root causes of product failures are identified and recorded by design engineers

Strongly agree Agree Neutral Disagree Strongly disagree

13. Root causes of product failures are identified and recorded by service engineers

Strongly agree Agree Neutral Disagree Strongly disagree

14. The product field failure data allows for subsequent analysis of reoccurring problems across product families

Strongly agree Agree Neutral Disagree Strongly disagree

15. Product field failure data is easily accessible for conducting product FMEA

Strongly agree Agree Neutral Disagree Strongly disagree

16. Product field failure data is recorded in a useful format for conducting product FMEA

Strongly agree Agree Neutral Disagree Strongly disagree

17. Product field failure data is of sufficient accuracy for conducting product FMEA

Strongly agree Agree Neutral Disagree Strongly disagree

18. Product field failure data is readily available when conducting product FMEA

Strongly agree Agree Neutral Disagree Strongly disagree

19. The feedback process of product field failure data to design department is well understood by design engineers

Strongly agree Agree Neutral Disagree Strongly disagree

20. The feedback process from service department to product design is clearly defined and measurable (for e.g. in guidelines, manuals, process flow diagrams exist)

Strongly agree Agree Neutral Disagree Strongly disagree

21. Performance of the level and quality of feedback from the service department to product design department is periodically assessed

Strongly agree Agree Neutral Disagree Strongly disagree

22. The mop-mis database is a useful tool in the feedback process from service department to design department

Strongly agree Agree Neutral Disagree Strongly disagree

23. Product field failure MOP-MIS database is actively used for product FMEA

Strongly agree Agree Neutral Disagree Strongly disagree

24. The product field failure MOP-MIS database user friendly

Strongly agree Agree Neutral Disagree Strongly disagree

25. The existing classification of failure modes recorded in MOP-MIS is appropriate for conducting product FMEA

Strongly agree Agree Neutral Disagree Strongly disagree

26. The project team members and FMEA facilitators been trained to use product field failure data for product FMEA

Strongly agree Agree Neutral Disagree Strongly disagree

27. Changes are necessary in the current product field failure feedback from service department to design department if the practise of product FMEA is to be improved

Strongly agree Agree Neutral Disagree Strongly disagree

THANK YOU

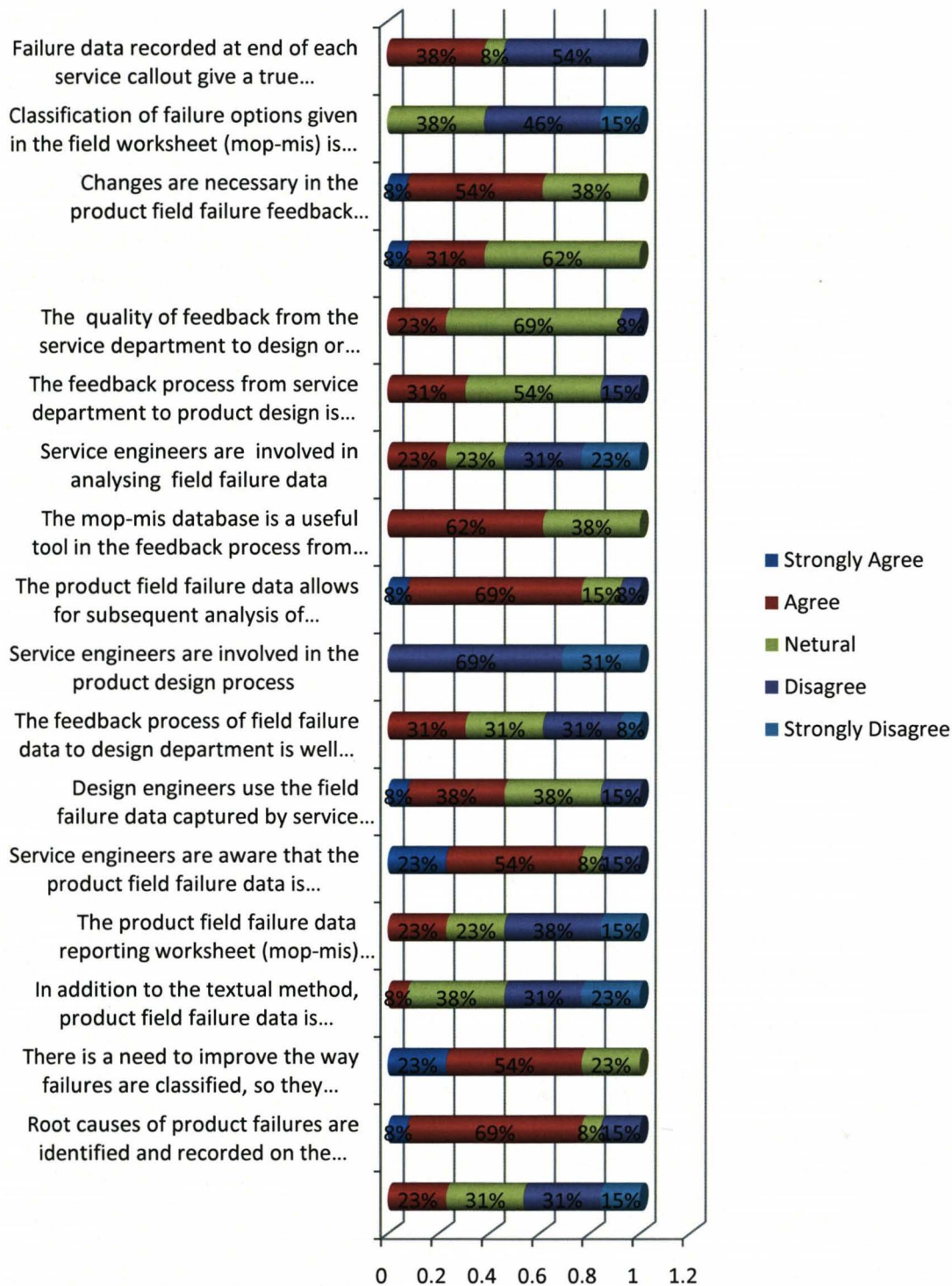
APPENDIX V: BAR CHART SHOWING QUESTIONNAIRE RESPONSES

Questions	Strongly Agree	Agree	Netural	Disagree	Strongly Disagree
I have a good level of understanding on Failure Mode and Effect Analysis (FMEA) and its application in product development		23%	31%	31%	15%
Root causes of product failures are identified and recorded on the field worksheet (mop-mis)	8%	69%	8%	15%	
There is a need to improve the way failures are classified, so they better represent the actual failures in the field	23%	54%	23%		
In addition to the textual method, product field failure data is captured in other useful ways (e.g. video, audio, pictures)		8%	38%	31%	23%
The product field failure data reporting worksheet (mop-mis) captures all the necessary information about product failure for future corrective action		23%	23%	38%	15%
Service engineers are aware that the product field failure data is captured for the purposes of future product improvement	23%	54%	8%	15%	
Design engineers use the field failure data captured by service engineers for the purpose of product improvement	8%	38%	38%	15%	
The feedback process of field failure data to design department is well understood by service engineers		31%	31%	31%	8%
Service engineers are involved in the product design process				69%	31%
The product field failure data allows for subsequent analysis of reoccurring problems across product families	8%	69%	15%	8%	
The mop-mis database is a useful tool in the feedback process from service department to design or R&D		62%	38%		
Service engineers are involved in analysing field failure data		23%	23%	31%	23%
The feedback process from service department to product design is clearly defined and measurable (for e.g. in guidelines, manuals, process flow diagrams exist)		31%	54%	15%	
The quality of feedback from the service department to design or R&D is regularly assessed		23%	69%	8%	
The product field failure data is a useful input to System level Failure Mode and Effect Analysis	8%	31%	62%		
Changes are necessary in the product field failure feedback process from service to design or R&D for the purpose of product improvement	8%	54%	38%		
Classification of failure options given in the field worksheet (mop-mis) is adequate for characterising product failures in the field.			38%	46%	15%
Failure data recorded at end of each service callout give a true reflection of the problems in the field.		38%	8%	54%	

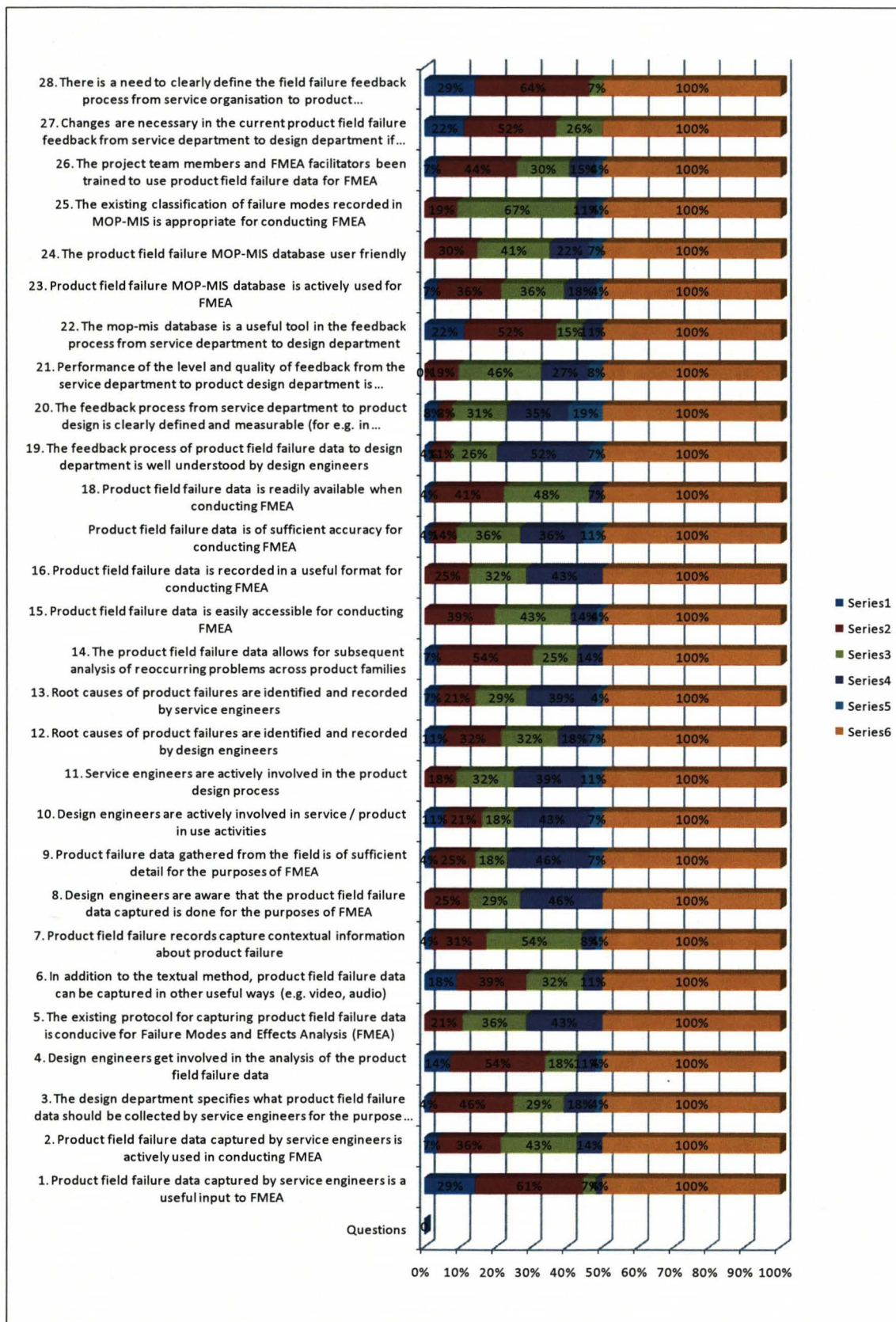
Service Engineers questionnaire survey responses

Questions	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1. Product field failure data captured by service engineers is a useful input to FMEA	29%	61%	7%	4%	
2. Product field failure data captured by service engineers is actively used in conducting FMEA	7%	36%	43%	14%	
3. The design department specifies what product field failure data should be collected by service engineers for the purpose of FMEA	4%	46%	29%	18%	4%
4. Design engineers get involved in the analysis of the product field failure data	14%	54%	18%	11%	4%
5. The existing protocol for capturing product field failure data is conducive for Failure Modes and Effects Analysis (FMEA)		21%	36%	43%	
6. In addition to the textual method, product field failure data can be captured in other useful ways (e.g. video, audio)	18%	39%	32%	11%	
7. Product field failure records capture contextual information about product failure	4%	31%	54%	8%	4%
8. Design engineers are aware that the product field failure data captured is done for the purposes of FMEA		25%	29%	46%	
9. Product failure data gathered from the field is of sufficient detail for the purposes of FMEA	4%	25%	18%	46%	7%
10. Design engineers are actively involved in service / product in use activities	11%	21%	18%	43%	7%
11. Service engineers are actively involved in the product design process		18%	32%	39%	11%
12. Root causes of product failures are identified and recorded by design engineers	11%	32%	32%	18%	7%
13. Root causes of product failures are identified and recorded by service engineers	7%	21%	29%	39%	4%
14. The product field failure data allows for subsequent analysis of reoccurring problems across product families	7%	54%	25%	14%	
15. Product field failure data is easily accessible for conducting FMEA		39%	43%	14%	4%
16. Product field failure data is recorded in a useful format for conducting FMEA		25%	32%	43%	
Product field failure data is of sufficient accuracy for conducting FMEA	4%	14%	36%	36%	11%
18. Product field failure data is readily available when conducting FMEA	4%	41%	48%	7%	
19. The feedback process of product field failure data to design department is well understood by design engineers	4%	11%	26%	52%	7%
20. The feedback process from service department to product design is clearly defined and measurable (for e.g. in guidelines, manuals, process flow diagrams exist)	8%	8%	31%	35%	19%
21. Performance of the level and quality of feedback from the service department to product design department is periodically assessed	0%	19%	46%	27%	8%
22. The mop-mis database is a useful tool in the feedback process from service department to design department	22%	52%	15%	11%	
23. Product field failure MOP-MIS database is actively used for FMEA	7%	36%	36%	18%	4%
24. The product field failure MOP-MIS database user friendly		30%	41%	22%	7%
25. The existing classification of failure modes recorded in MOP-MIS is appropriate for conducting FMEA		19%	67%	11%	4%
26. The project team members and FMEA facilitators been trained to use product field failure data for FMEA	7%	44%	30%	15%	4%
27. Changes are necessary in the current product field failure feedback from service department to design department if the practice of FMEA is to be improved	22%	52%	26%		
28. There is a need to clearly define the field failure feedback process from service organisation to product design/development process	29%	64%	7%		

Design engineers questionnaire survey response



Service Engineers questionnaire Chart



Design engineers questionnaire survey chart

Appendix VI: Validation exercise letter sent to industrial experts

PhD Research: Design for Service: An empirical exploration of the antecedents of an effective feedback process from service-to-design

Researcher:

Dupe Ajayi, Affiliation: Cranfield University, UK

Supervisors:

Dr Palie Smart: Affiliation: Cranfield University, UK

Dear Sir,

Research Framework Validation

I am a PhD student working on the above research topic. I would like to solicit your support and time in participating in a 1 hour interview session to validate my research framework. My research focus is on improving the effectiveness of the feedback process from service-to-design. The objectives of this interview are as follows:

- To validate the conceptual ideas of the proposed framework
- To understand the existing feedback process from service-to-design within your organisation
 - How effective is the process?
 - To understand the possible impact of implementing the framework within your organisation context
 - How do you think the proposed framework would influence the feedback process from service-to-design?
- To assess the applicability of the framework in the context of your organisation
 - What benefit would it provide to your existing feedback process?
 - What difficulty would you expect in implementing this framework?

The outcome of the interview will be used for refining the proposed framework. I will be giving a brief presentation about the research background and findings from the investigation using scenarios.

With your prior permission I shall seek to record the interview. I can assure you of absolute **confidentiality** and **anonymity** in dealing with the information you may provide. I also promise to share the results/findings of the research with your company by submitting a copy to you on completion of the research project.

Please, do not hesitate to ask for further clarification where any question(s) is/are not clear enough. I look forward to your early response and proposed dates of your availability. Please email them to me at the address below.

Yours Sincerely,

Dupe Ajayi

Doctoral Research Student

Cranfield University

m.o.ajayi@cranfield.ac.uk

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Mobile: 07930527550