CRANFIELD UNIVERSITY

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A3 THINKING APPROACH TO SUPPORT LEAN PRODUCT AND PROCESS DEVELOPMENT

SCHOOL OF APPLIED SCIENCES

PhD Thesis
Academic Year: 2009 - 2013

Academic Supervisors: Dr. Ahmed Al-Ashaab and Dr. Essam Shehab
March 2013

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This thesis is submitted in fulfilment of the requirements for the degree of PhD

ABSTRACT

This research project aims to develop a novel A3 thinking approach to support knowledge driven design that aids the generation of decision making within a Lean Product and Process Development (LeanPPD) environment. This research comprises the development of a new A3 template as a technique of problem solving in product design, the adoption of a reflection practice structured in a new A3 template for knowledge capture and sharing, and the generation of the process of using the A3 thinking approach for effective implementation. Providing useful knowledge as a design reference to generate decision making at the initial stages of product development in product design helps the designers to prevent recurrence of the same problem, eliminate design mistakes and enhance design decision. In order to achieve a novel A3 thinking approach, a research methodology consisting of four phases was developed. The first phase synthesises the A3 best practice through literature and documentation reviews. The gap analysis and results from the reviews have identified several problem-solving approaches and learning cycles that have to be considered in the research. The second phase is to evaluate the approaches and their impacts and applications in product design. In order to complete this, several research methods are selected and performed (e.g. focus group and semi-structured interview) within the collaborative companies. The third phase is to develop the A3 thinking approach by utilising the LAMDA learning cycle, developing a new A3 template or so-called A3LAMDA, adopting the reflection practice and generating the process of using the new A3 thinking approach. Finally, the validation of the new A3 thinking approach through industrial case studies and expert judgements have been performed. This approach has been implemented in the automotive sector and was applied to four industrial case studies and six A3LAMDA reports were collected. As a result of the findings of this research, the utilisation of the A3 thinking approach aided the generation of knowledge driven design in product design by integrating the knowledge management capabilities; knowledge creation, capture and sharing.

Keywords: A3 thinking, A3LAMDA, lean thinking, lean design, design problem solving, knowledge driven design

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LIST OF PUBLICATIONS

1. N. Mohd Saad, A. Al-Ashaab, M. Maksimovic, L. Zhu, E. Shehab, P. Ewers, and A. Kassam, (2013), "A3 Thinking Approach to Support Knowledge Driven Design", *International Journal of Advanced Manufacturing Technology, DOI: 10.1007/s00170-013-4928-7.*

2. N. Mohd Saad, A. Al-Ashaab, E. Shehab, and Maksimovic, M. (2012), "A3 Thinking Approach to Support Problem Solving in Lean Product and Process Development", *19th ISPE International Conference on Concurrent Engineering*, Vol. 2, pp. 871-882, 03-07 September 2012, University of Applied Sciences, Trier, Germany, Springer.

3. N. Mohd Saad, M. Flores, I. Alammari and A. Al-Ashaab, (2012), "Developing an A3 Thinking Methodology to Enhance the Production Process", *10th International Conference on Manufacturing Research*, Vol.2, pp. 668-673, 11-13 September 2012, Aston University, Birmingham, United Kingdom.

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TABLE OF ACRONYMS

Terms	Details of Short Terms	Terms	Details of Short Terms
8D	8 Disciplines	LeanKLC	Lean Knowledge Life Cycle
BOM	Bill of Materials	LeanPPD	Lean Product and Process Development
CE	Conducted Emissions	OEM	Original Equipment Manufacturer
CI	Conducted Immunity	PAF	Problem Analysis Flowchart
CS	Case Study	PCB	Printed Circuit Board
CU	Cranfield University	PDS	Product Design Specification
DAB	Digital Audio Broadcasting	PWM	Pulse-Width Modulation
DQC	Design Question Checklist	QFD	Quality Function Deployment
DR	Design Rule	RCA	Root Cause Analysis
DSC	Design Statement Checklist	RE	Radiated Emission
DUT	Device Under Test	Rec	Recommendation
EMC	Electromagnetic Compatibility	RI	Radiated Immunity
EMI	Electromagnetic Interference	RIA	Reflection In Action
ESD	Electrostatic Discharge	ROA	Reflection On Action
Fc	Function	RPN	Risk Priority Number
FM	Failure Mode	SBCE	Set-Based Concurrent Engineering
FMEA	Failure Mode and Effect Analysis	SPI	Serial Peripheral Interface
FTT	First Time Through	TPS	Toyota Production System
KLC	Knowledge Life Cycle	TRIZ	Theory of Inventive Problem Solving
LAMDA	Look-Ask-Model-Discuss-Act	UK	United Kingdom
LDG	Lean Design Guidelines	VES	Visteon Engineering Services

TABLE OF THESIS GLOSSARIES

Thesis Terms	Definition
A3 thinking approach	A new design problem solving approach that provides the A3LAMDA template for product design to support knowledge-driven design.
Knowledge driven design	Knowledge gathered from the integrated actions of visualising, solving, learning, reflecting and creating using the A3LAMDA template during the design problem solving.
A3LAMDA template	A new A3 template (size standard A3 paper) structured from the customised elements as a tool for problem solving guides by the LAMDA learning cycle.
LAMDA learning cycle	A cycle of knowledge creation that contains 5 stages, which are Look, Ask, Model, Discuss and Act.
Knowledge rich environment	An environment at product design is considered as knowledge-rich when it gives potential for the design team to capture and obtain useful knowledge. The latter has been either previously used to solve design problems or newly created during problem solving activities in product design.
Useful Knowledge	Knowledge that is derived from the systematic process and enables the designers to understand the linkage between hypotheses and practice which results in a new learning and understanding. Hence, to formulate it into design rule or design recommendation to be shared and communicated.
LeanPPD Environment	Knowledge based user-centric design and development environment to support value creation to the customer based on lean thinking.
Failure Documentation template	A template to document the identified design problem.

Chapter

1

1 INTRODUCTION

1.1 Research Background

Manufacturing enterprises have recognised the importance of creating a knowledge environment to support product development. This aims to enhance the quality of decision making throughout the development process as well as to reuse and share the knowledge in order to address the different product development challenges. During the design process, the designers encounter different problems that need to be addressed and solved. As such, a problem-solving skill and approach are required to support the design process. The solutions from solving design problems create new knowledge, and such knowledge becomes important in the next stages of the product's development, as well as for any future project(s). Several pieces of research have addressed the importance of knowledge in product design, design rationale and design intent (Sun et al., 2010; Tang et al., 2007; Ullman, 2001; Sim and Duffy, 1994); however, this is not related to the theme of this thesis which is to capture and share the knowledge created from solving problems that have been encountered in the design process.

Solving a problem in product design will generate two important outputs: the obtained solution and the created knowledge. However, some challenges hinder the full utilisation of the created knowledge; most designers are more interested in reaching and implementing the solution rather than capturing and visualising the created knowledge in an informative and simple manner that could be useful for current and future projects (Mohd Saad et al., 2012(a)). Therefore, there is a need for a problem-solving approach that could be implemented during the design stage which ensures knowledge creation and capture, as well as the provision of a knowledge-rich environment. Such an approach will also contribute to the generation of a better design solution. There is also a need for a mechanism which allows the captured knowledge to be shared and communicated with other engineers and projects. Due to the high level of competition involved in a product launch, designers have to solve design problems quickly (Ulrich and Eppinger, 2008). Consequently, time limitations and lack of suitable tools can hinder the capture of knowledge generated from the problem solving process. In addition, it is difficult to locate and use the existing knowledge from different sources, such as databases and a huge range of documentation. Such a lack of support for the designer's decision making in utilising relevant knowledge is likely to lead to an increased risk of design iterations. Sharing knowledge among designers and engineers during product design and development is important, otherwise bad decisions in design may be taken as well as increasing the communication barriers among the team (Borches and Bonnema, 2010).

This thesis presents a novel approach to problem solving in product design. The novelty of the approach is in three areas; firstly, providing a simple template as a technique to share and support the communication of that useful knowledge; secondly, presenting a way to capture the created useful knowledge; and thirdly, developing a process to solve design problems based on a new A3 template. Within the context of this thesis, the author has defined useful knowledge as knowledge derived from the systematic process which enables designers to understand the linkage between hypotheses and practice on a simple template which results in new learning and understanding. This will enable the designers to solve a problem whilst enriching the environment of knowledge creation and capture efficiently to be shared in the future. The combination of these aspects is called the 'A3 thinking' approach and it aims to facilitate the generation of knowledge-driven design to support decision making and hence, reduce design mistakes in future.

Traditional A3 thinking is defined as an approach to solving problems and finding opportunities for improvement in manufacturing on the shop-floor, and to find an opportunity for improvement (Anderson et al., 2011). The traditional A3 report was developed by the Toyota Motor Corporation in the early 1960s as a technique to solve problems and provide continuous improvement. This report was structured into seven elements, namely: 1) Background, 2) Current condition, 3) Future goal, 4) Root cause analysis, 5) Countermeasures, 6) Implementation plan and 7) Follow-up actions (Sobek and Smalley, 2008). These elements are guided by the learning cycle of continuous improvement; Plan-Do-Check-Act (PDCA). However, the traditional A3 thinking approach does not integrate the aspects of knowledge creation, capture and sharing and has not been developed and used for product design.

To overcome such limitations of the traditional A3 thinking, the proposed new A3 thinking approach in this research involved a range of applications to be used in product design, such as design problem solving, idea generation, knowledge communication and visualisation, knowledge reuse for new projects and lessons learned. This range of applications will enable designers to make decisions in a knowledge-rich environment. According to Holmqvist and Pessi (2006), a knowledge-rich environment allows the provision of customer-driven products and services in a fast changing market. This definition however, seems quite generic and for the scope of this research, the environment of product design is considered as knowledge-rich when it provides potential for the design team to capture and obtain useful knowledge. The latter has either been previously used to solve design problems or been newly created during problem solving activities in the product design.

1.2 The LeanPPD Project

The research reported in this thesis is part of the Lean Product and Process Development (LeanPPD) project funded by the EU-FP7 (European Union - 7th Framework Programme). The project addresses the needs of European manufacturing companies for a new model that goes beyond lean manufacturing, to ensure the transformation of the enterprise into a lean environment (Al-Ashaab et al., 2010). The LeanPPD Project started early in 2009 and aims to develop a new model to create value and to eliminate non-value added throughout product design and development, based on proven knowledge and experience by lean thinking. This model aims to provide product realisation to the customer in terms of innovation and customisation, and quality as well as sustainable and affordable products (Al-Ashaab et al., 2010). The LeanPPD project involves twelve European partners, shown in Table 1-1, within different sectors: aeronautical, automotive and home appliances. Out of these twelve partners, five are industrial (Rolls-Royce, Volkswagen, Visteon, Indesit and SITECH) to serve the requirements of the tools, methodology and models being developed. In order to ensure the completeness of the work, the research team of Cranfield has involved six researchers and this will be discussed in Section 1.6.

No.	Partners	Short Names	Countries
1	Tecnalia	Tecnalia	Spain
2	Cranfield University	CU	UK
3	Rolls-Royce	R-R	UK
4	University of Warwick	WARWICK	UK
5	Institut für angewandte Systemtechnik Bremen	ATB	Germany
6	Volkswagen A.G.	VW	Germany
7	Ecole Polytechnique Fédérale de Lausanne	EPFL	Switzerland
8	Visteon Engineering Services Ltd	VES	UK
9	SISTEPLANT	SIS	Spain
10	Politécnico di Milano	POLIMI	Italy
11	Indesit	INDESIT	Italy
12	SITECH	SITECH	Poland

Table 1-1: List of LeanPPD Partners

1.3 Research Motivations

The research presents the A3 thinking as an approach to solving problems in product design and hence, to aid the generation of knowledge driven design. The latter aims to support the decision making for product design by capturing and providing useful knowledge created and captured from design solutions and documented in a simple manner. The research is proposed according to the following motivations:

- As a part of the LeanPPD project's enablers which also consider the problem solving approach and to stem the lean thinking at the initial stage in lean product development.
- Manufacturing companies who fail to make accurate decisions in the product design will increase by up to 75%-80% life cycle cost in product development (McCarthy et al., 2006; Mileham et al., 1993). Therefore, providing a simple and effective problem solving approach in product design through this research enables designers to capture and share the knowledge. As a result, the design mistakes will be avoided and the generation of decision making supported.
- The key principle in lean application is empowerment of the employees. This can only be achieved through extensive engagement in decision making, problem solving and continuous improvement (Vidal, 2007; Womack et al., 2007).
- Current problem solving approaches are not integrating knowledge creation, capture and sharing to support problem solving in product design.

1.4 Research Aim and Objectives

The research aim is to develop a novel A3 thinking as a product design problem solving approach to aid the generation of knowledge driven design to support decision making within a LeanPPD environment. The overall research objectives are to;

1. Synthesise the best practices of A3 thinking as a problem solving approach in product design through an extensive literature review.
2. Evaluate the different problem solving approaches and appreciate their applications for and impact on product design activity to create useful knowledge.

3. Develop an A3 thinking approach that will ensure inter-relations between the different problem solving approaches to aid the generation of knowledge driven design to support decision making.
4. Validate the A3 thinking approach through industrial business cases within the LeanPPD project.

1.5 Research Questions

The following research questions were formulated in order to guide the author to explore and identify the phenomenon to be studied.

Research Question 1: How the current practices of the problem solving approaches contribute to the process of design solution and learning cycle? This is link to the second research objective.

Research Question 2: How the current problem solving approaches satisfy the knowledge management capability to support knowledge driven design? This is link to the second research objective.

Research Question 3: How the new A3 thinking approach aid the generation of knowledge driven design to support decision making? This is link to the third research objective.

Research Question 4: How the new A3 thinking approach support a lean product and process development environment? This is link to the research aim.

The following section looks at the paradigm of LeanPPD, which explains the enablers and different tasks. Thus, the contribution of the research within the LeanPPD Cranfield University team can be examined.

1.6 LeanPPD Paradigm

The fundamental goal in the LeanPPD paradigm is to move from waste elimination to value creation using the integrated model and tools to enable effective product development (Al-Ashaab et al., 2010). LeanPPD believes that a significant change in enterprise performance can come from the adoption of lean thinking throughout the entire product lifecycle. Lean thinking supports companies in streamlining the product lifecycle, from the design and development phase onwards. In modern industry, there are many examples of waste within product development: both in the process (e.g. poor communication) and in the product (e.g. high defect rate). Figure 1-1 shows the key research areas of the Cranfield University team that represent the LeanPPD enablers. These are Lean Design Guidelines, Lean Knowledge Life Cycle (LeanKLC), Cost Model, A3 Thinking Approach, Failure Documentation and Set-Based Concurrent Engineering (SBCE).

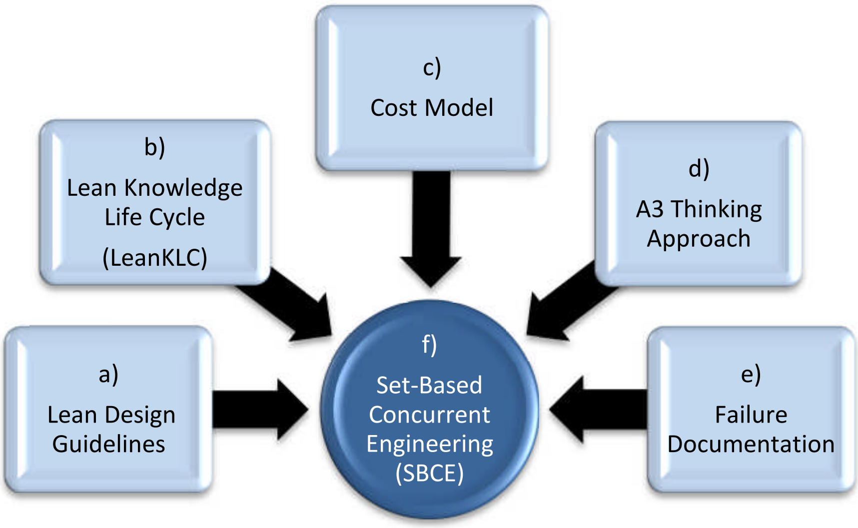


Figure 1-1: The Research Areas of LeanPPD Enablers at Cranfield University

The aim of each research area is presented and the overall contribution to the LeanPPD model is described as follows:

a) Lean Design Guidelines

- This research is led by Mr. Alam to develop Lean Design Guidelines that allow the representation of customers' and company values into a set of conceptual lean design-based definitions of product lifecycle features that are affected by lean principles (Alam, 2013).

b) Lean Knowledge Life Cycle

- This research is led by Mr. Maksimovic to develop Lean Knowledge Life Cycle (LeanKLC) as a methodology to capture, re-use and create knowledge in the Lean Product and Process Development (LeanPPD) environment (Maksimovic, 2012).

c) Cost Model

- This research is led by Mr. Wasim to develop a cost modelling system for Lean Product and Process Development (LeanPPD) to support proactive decision making and mistake elimination at the design stage (Wasim, 2012).

d) A3 Thinking Approach

- This research is led by Mrs. Mohd Saad to develop a novel A3 thinking as a product design problem solving approach to aid the generation of knowledge driven design to support decision making within a LeanPPD environment (Mohd Saad et al., 2012(a)).

e) Failure Documentation

- This research is led by Mr. Zhu to integrate failure documentation with traditional A3 template to improve product design quality (Zhu, 2012).

f) Set-Based Concurrent Engineering

- This research is led by Mr. Khan to develop a novel Lean PPD model, Set-Based Concurrent Engineering (SBCE) represents the structured combination of product development activities which supports the focus on value creation, creating a knowledge-based environment and building a continuous improvement culture (Khan, 2012).

All these researches are related and were integrated as a LeanPPD model. The inter-relation of these researches is to capture and develop a knowledge-based environment in order to support LeanPPD. For example, SBCE is focused on the application of lean for the entire product development, but a lean approach needs to be applied from the initial phase of the product life cycle which is the design concept.

This is supported by Lean Design Guidelines. In order to enable the creation and realisation of proven knowledge during the product development process, the LeanKLC helps to capture knowledge, represent and reuse processes to conform to the principles of lean thinking and support its implementation. The impact of the application of lean in product life cycles has to be measured in terms of qualitative and quantitative factors. The qualitative factors such as design performance, customer's values and manufacturability are important for designers, while quantitative factors such as cost are critical to the company. Thus, a Cost Model helps to ensure that the implementation of the LeanPPD does not increase the overall cost of the product. In this research, two enablers are most related which are LeanKLC and Failure Documentation. The failure documentation helps the new A3 thinking by capturing necessary information and data from the person who identified the design problem or document the failed test of the design validation. This aid the smooth transformation of the data into the new A3 template in elements 2 and 3. While LeanKLC is to compile the captured knowledge from the new A3 reports hence to ensure the knowledge will be effectively shared and re-used within the company.

The LeanPPD model was developed based on three key principles; value focus, knowledge based environment (KBE) and continuous improvement (CI) as shown in Figure 1-2. Khan (2012) explains the three key principles as follows; the value-focus was differentiated between process/enterprise values and an example of process value is knowledge, while the KBE was derived from mechanisms of knowledge capture, representation and communication support allowing more to be learned about design alternatives. KBE also ensures that the factual knowledge flows in the right place and person at the right time. LeanPPD also focuses on a culture of continuous improvement as a part of lean product development (Lean PD) to incorporate improvements. These key principles, however, need to be utilised by the chief engineer as technical leader throughout the entire product development process to support SBCE. Based on Figure 1-2, the contribution of the new A3 thinking approach within the LeanPPD model focused on knowledge-based environment and continuous improvement, is the documentation and visualisation of the useful knowledge in a simple manner in order to support designers make right decisions. The useful knowledge is obtained and captured from the continuous process of problem solving, where the problems are identified while the solutions are documented. The captured and documented useful knowledge in the knowledge-based environment enhances decision making and prevents a recurrence of design problems in current and future design projects.

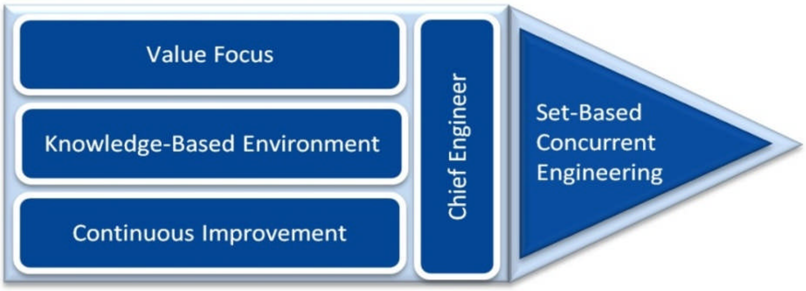


Figure 1-2: The LeanPPD Model (Khan, 2012)

1.7 Industrial Collaborator

The industrial collaborator is one of the industrial partners in the LeanPPD consortium for the automotive sector and is described as follows:

Visteon Engineering Services Ltd

Visteon Engineering Services (VES) Ltd. was established in 2007 and manufactures components which the vehicle Original Equipment Manufacturer (OEM) assembles into the vehicle. The design of a product is achieved collaboratively between the OEM and Visteon. The OEM wants to control the appearance of the product in line with its brand strategy, while Visteon brings the technology to satisfy the overall needs of the OEM. The electronic components of the automotive vehicles are increasingly critical to the safety and functional features; hence, becoming more challenging to designers in auto industries. Higher consumer demand for advanced safety and operational features, such as mobile communications, security and entertainment systems makes the vehicle components more complex. The demands can only be achieved through the use of electronic system installed in the vehicle (Liu, 2004) which can form serious environmental pollution called the Electromagnetic Interference (EMI). The EMI may cause malfunctions for electrical or electronic products, hazardous atmospheres and even worse have a direct effect on human tissue (Williams, 2007). The threat of EMI can be controlled by adopting the practices of Electromagnetic Compatibility (EMC). EMC is the ability of a device to control and prevent interference, or EMI (Burneske, 1999) which means all the electronic and electrical equipment must pass the EMC requirements. The EMC requirements commonly consist of emission and immunity elements and fall into four types of testing (RE, CE, RI, and CI) as shown in Table 1-2. This large scale system faces challenges driven by cost and designs that overwhelm the complexity of the system level EMC design (Moore, 2003). Therefore, the author has focused on EMC design issues for the case studies in Chelmsford, United Kingdom, which is the European design and development centre of excellence.

EMC Testing Requirements	
Emissions	**Immunity**
The emission is transmission of EMI from non compliant devices and in particular radiated and conducted radio frequency interference (RFI). a) Radiated Emission (RE): The component of Radio Frequency (RF) energy that is transmitted through a medium as an electromagnetic field. b) Conducted Emission (CE): The component of RF energy that are transmitted through a conductive medium as an electromagnetic field, generally through a wire or interconnection cables.	The immunity is the detrimental effects on susceptible devices of EMI in forms that include electrostatics discharge (ESD) and other forms of electrical overstress (EOS). a) Radiated Immunity (RI): The relative inability of a product to withstand EMI that arrives via free-space propagation. b) Conducted Immunity (CI): The relative inability of a product to withstand electromagnetic energy that reaches it through external cables, power cords and other means.

Table 1-2: Electromagnetic Compatibility testing Requirements (Montrose, 2000)

1.8 Thesis Structure

This thesis is divided into seven chapters as shown in Figure 1-3. The following highlights and describes the remainder of the thesis structure. Chapter two (Research Methodology) explores the scope and limitations of the research methodology, explaining how the data was collected and analysed. Chapter three (Review and Analysis of Problem Solving Approaches) reviews the importance of product development, current problem solving approaches and knowledge management capabilities. The gap in the research is also highlighted. Chapter four (Industrial Perspectives of Problem Solving Approaches and Knowledge Capture) describes and analyses the LeanPPD methodological approaches and data collection methods of literatures and documentation reviews, semi-structured interviews, direct observation and focus group. Chapter five (Development of a Novel A3 Thinking Approach) explains the development of the new A3 thinking approach to aid the generation of knowledge driven design to support decision making within a LeanPPD environment. Chapter six (Validation) presents the research validation methods of industrial case studies and expert judgements conducted at the collaborating industry. Chapter seven (Discussion, Conclusions and Future Work) discusses the research results, research limitations and contributions. It also provides research conclusions and points out future possibilities.

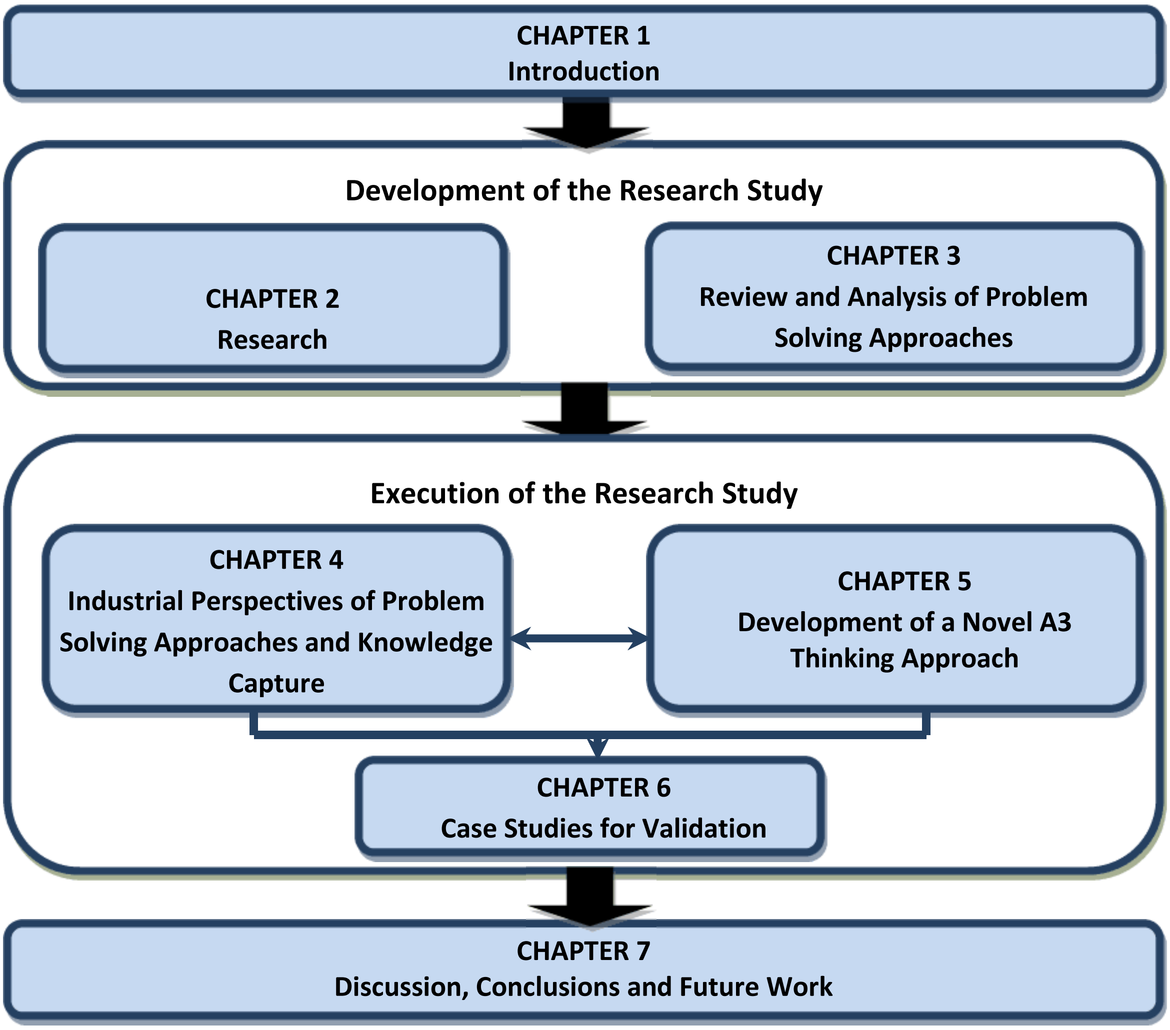
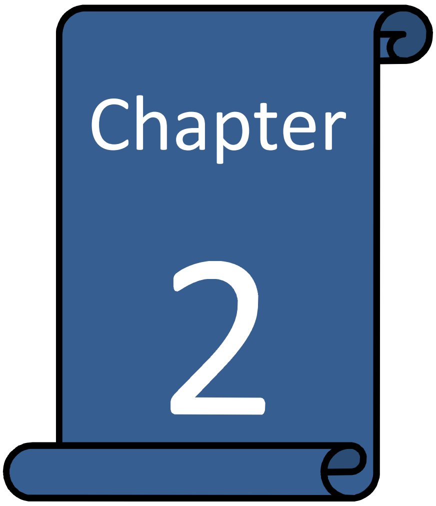


Figure 1-3: Thesis Structure



2 RESEARCH METHODOLOGY

2.1 Introduction

The essence of the first chapter was the origin of the research background and motivation that led to the research proposal. In order to address and achieve the research aim and objectives presented in Section 1.4, the appropriate research methodology has been developed aiming to interpret and capture the best practices of the problem solving approaches in product design, and hence to validate the developed approach. Therefore, this chapter has two purposes:

- To describe the origin and rationale of the selected and utilised methodological approaches in order to achieve the research aim and objectives;
- To explain the adopted research methodology.

Lehaney and Vinten (1994) have described the methodology as "the modelling process which includes hard and soft systems approaches, and the ways in which the relevant variables are chosen for a model, and how reality is concomitantly simplified". In the remainder of this chapter, Section 2.2 explains the development of the research study and also the origin and relevance of the selected approaches. The adopted research methodology is discussed in Section 2.3. Finally, the chapter summary is presented in Section 2.4. The content of this chapter and the details of the selected approaches are illustrated in Figure 2-1.

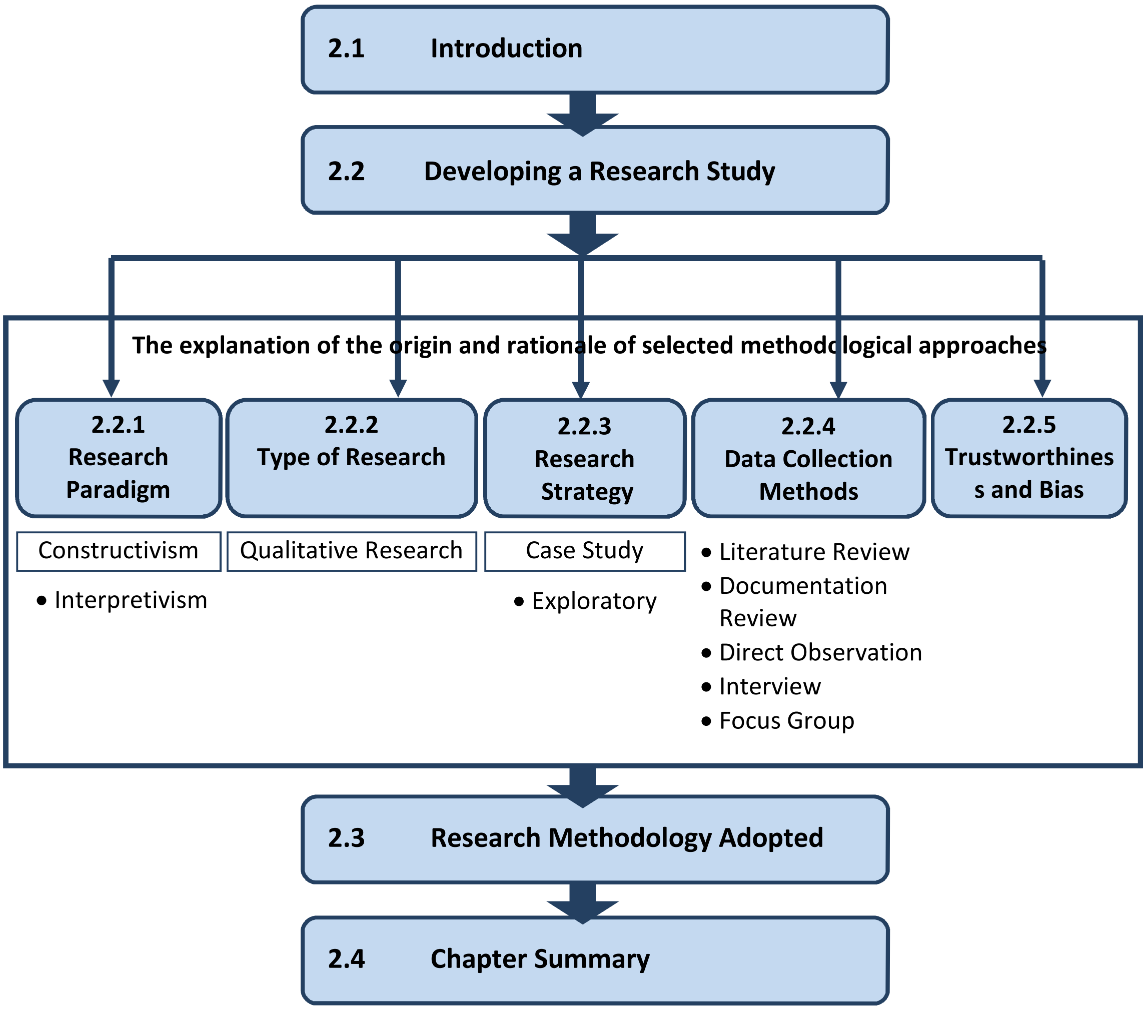


Figure 2-1: Structure of Chapter 2

The following section explains the development of a research study whilst elaborating on the origin and rationale of the selected methodological approaches and adopted methodology.

2.2 Developing a Research Study

The development of a research study is a very important aspect on which to focus and provides both the directions for the study and also constitutes an organised way to ensure that the research questions explained in Section 1.5 are appropriately and sufficiently answered. A research study is defined as “a systematic investigation and study in order to establish facts and reach new conclusion” whilst a research philosophy is defined as “the study of the fundamental nature of knowledge, reality and existence" (Soanes et al., 2004). The research study is an organised scientific procedure or activity that is designed to determine the answer to research questions by using different methods. It is very important as it allows contribution to knowledge.

2.2.1 Research Paradigm

The "research paradigm is a set of methods that all exhibit the same pattern or element in common". It contains several research activities, with different classified methods such as the literature review, survey, interview and experiments being used to obtain data (Meredith et al., 1989). Onwuegbuzie and Leech (2005) state that the research paradigm is "a function of the extent to which the author is prepared to conform to its underlying assumptions". The research paradigm contains several philosophical assumptions such as epistemology, ontology, axiology and methodology (Collis and Hussey, 2009). Therefore, it is very important for the social research to encounter the concepts of ontology (reality) and epistemology (theory of knowledge) as the author is exploring the real world that builds theory of knowledge, which in turn is valid through appropriate methodologies. The descriptions of the two selected philosophical assumptions are as follows:

- Ontology: is the branch of philosophy concerned with the nature of reality and existence and their relations.
- Epistemology: "the science or study of being that includes claims about what exists, what it looks like, what units make it up and how these units interact with each other" (Blaikie, 1993).

Table 2-1 illustrates two types of ontology assumption, namely objectivism and constructivism, whilst Table 2-2 describes three types of epistemology assumptions. According to these descriptions, constructivism and interpretivism are the best fits to be adopted for this research as constructivism is based on the knowledge that can be constructed through social interaction with the environments. This is suited to the interpretivism assumption that the subjective meaning is constructed through social action. Using the selected research paradigm enables the author to gain an in-depth understanding of the design issues and challenges, and knowledge management in product design.

Ontology	
Objectivism	**Constructivism**
Objectivism is an ontological position that asserts that social phenomena and their meanings have an existence that is independent of social actors. It implies that social phenomena and the categories that we use in everyday discourse have an existence that is independent or separate from actors.	Constructivism/constructionism is an ontological position which asserts that social phenomena and their meanings are continually being accomplished by social actors. It implies that social phenomena and categories are not only produced through social interaction but they are in a constant state of revision.

Table 2-1: Types of Ontology Assumption (Bryman and Bell, 2007)

Epistemology		
Positivism	**Interpretivism**	**Realism**
Positivism is an epistemological position that advocates the application of the methods of the natural sciences to the study of social reality and beyond. It states that only authentic knowledge is knowledge and that such knowledge can only come from positive affirmation of theories through strict scientific methods.	Interpretivism is taken to denote an alternative to the positivist orthodoxy that has held way for decades. It is predicted from the view that a strategy is required that respects the differences between people and the objects of the natural sciences and therefore requires the social scientist to grasp the subjective meaning of social action.	Realism shares two features with positivism: a belief that the natural and social sciences can and should apply the same kinds of approach to the collection of data and to explanation, and a commitment to the view that there is external reality to which scientists direct their attention.

Table 2-2: Types of Epistemology Assumption (Bryman and Bell, 2007)

This section explained and selected the appropriate research paradigm suited to this research. This led the author to investigate types of research based on the selected research paradigm.

2.2.2 Types of Research

Research can be categorised into two common types, qualitative and quantitative (Burns, 2000; Robson, 2011). Qualitative research refers to data and information in the form of words whilst quantitative research is essentially numerical in form, e.g. numerical modelling. Recently however, mixed method research is increasingly being articulated. Several definitions have emerged and been attached to research practices. Johnson et al. (2007) define mixed method research as “the type of research in which an author or team of authors combines elements of qualitative and quantitative research approaches (e.g. use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for purposes of breadth and depth of understanding and corroboration”. However, the mixed method research is not suitable for this research as collection of the complex design problems and approaches does not lead to quantitative data, thereby being difficult to quantify. The qualitative and quantitative research based on classification of assumptions, purpose, method and role of the author are compared in Table 2-3.

	Types of Research	
	Qualitative Research	**Quantitative Research**
Assumptions	• Reality socially constructed • Variables complex and interwoven; difficult to measure • Events viewed from informants’ perspective • Dynamic quality of life	• Facts and data have an objective reality • Variables can be measured and identified • Events viewed from outsiders’ perspective Static reality of life
Purpose	• Interpretation • Contextualization • Understanding the perspectives of others	• Prediction • Generalization • Causal explanation
Method	• Data collection using participant observation, unstructured interviews • Concludes with hypothesis and grounded theory • Emergence and portrayal • Inductive and naturalistic • Data analysis by themes from informants • Data reported in language of informant • Descriptive write-up	• Testing and measuring • Commences with hypothesis and theory • Manipulation and control • Deductive and experimental • Statistical analysis • Statistical reporting • Abstract impersonal write-up
Role of the author	• Author as instrument • Personal involvement • Empathic understanding	• Author applies formal instruments • Detachment • Objective

Table 2-3: Comparison of Qualitative and Quantitative Research (Burns, 2000)

The detailed comparisons of qualitative and quantitative research are examined further in order to support the selection of the type of research, as shown in Table 2-4, which indicates the advantages and disadvantages of qualitative and quantitative research.

<table>
<tr><th rowspan="2">Types of Research</th><th colspan="2">Types of Research</th></tr>
<tr><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>Qualitative Research</td><td>• Unlimited research studies
• Easy to organise
• Gather the information, ideas and improvements
• Economical
• Direct contact with participants</td><td>• Imprecise measurements
• Dependent on author’s skills
• Possible bias
• Very time consuming</td></tr>
<tr><td>Quantitative Research</td><td>• Less time for research setting
• Precise measurements
• Allows for statistical comparison
• Definitive and standardised</td><td>• Limited research studies (e.g.: psychology & psychiatry)
• Costly
• Narrower data and information
• Lacks flexibility
• Results are limited</td></tr>
</table>

Table 2-4: The Advantages and disadvantages of the Qualitative and Quantitative Research

Taking into account Table 2-3 and Table 2-4, qualitative research is the best fit for this research. According to the previous judgements of the research paradigm, explained in sub-section 2.2.1, qualitative research constitutes the most useful research philosophy to support the selection of type of research. For example, Johnson et al. (2007) state that the constructivism which was selected for this research is connected to qualitative research, whereas objectivism is connected to quantitative research. Goldkuhl (2012) and Trauth (2001) also defined that qualitative research is most frequently influenced by and associated with interpretivism.

Qualitative research is linked to the other research methods (e.g.: data collection and interviews) as a dynamic process in order to discover the design problems and develop a simple and effective problem solving approach in product design while being used to aid the generation of a knowledge driven design. In addition, all the data and artefacts from the collaborating company were collected and reviewed as documents and texts instead of as numerical formats. In a nutshell, qualitative research provides a detailed understanding of a design problem by exploring the perspectives in great depth, whereas quantitative research provides a more general understanding of a design problem by measuring samples and variables (Creswell and Plano, 2011). Although some of the data collection is analysed in a statistical form, such as by using Microsoft Excel, it is not possible for the research to declare this as a mixed method, as the purpose is only to interpret in depth thereby providing rich descriptions. The following sub-section defines the qualitative methods for this research.

2.2.3 Research Strategy

Awasthy et al. (2012) define research strategy as “a structured set of guidelines or activities to assist in generating valid and reliable research results”. Creswell (1998) defines five qualitative research strategies, namely: grounded theory study, ethnographic study, case study, biography and phenomenology; whereas Robson (2011) concurs with the first three strategies as shown in Table 2-5.

Qualitative Research Strategy	Definition	Typical Features
Grounded Theory Study	Aims to generate theory based on the data collected from the study.	• Applicable to a broad range of phenomena • Mainly interview based • Provides comprehensive recommendations for data analysis and theory generation.
Ethnographic Study	Aims to capture, analyse, and explain how a group, organisation or community live and experience the world.	• Selection of a group, organisation or community • Author involvement in the setting • Use of observation.
Case Study	Detailed, intensive knowledge development about a single case, or a small number of related cases.	• Single/multiple case selection • Study of the case within its context • Use of various data collection techniques, such as observation and interviews.

Table 2-5: Three Qualitative Research Strategies (Robson, 2011)

The following sub-section describes the chosen research strategy used to carry out this research – the case study – as it is a combination of various data collection techniques which in turn provide good feedbacks.

Case Study

The case study refers to the definition provided within the Penguin Dictionary of Sociology, namely “the detailed examination of a single example of a class of phenomena, a case study cannot provide reliable information about the broader class, but it may be useful in the preliminary stages of an investigation since it provides hypotheses, which may be tested systematically with a larger number of cases" (Hill et al., 2000). However, Flyvbjerg (2006) found that this could be misleading in the field of social science studies, where some misunderstandings were raised, as presented in Table 2-6. He also provided revisions for the five misunderstandings as they are essential for social science studies and may be strengthened by the execution of multiple case studies. Exploring these five misunderstandings and revisions has led the author to choose the case study as a research strategy confidently.

No.	Misunderstandings	Revisions
1	General, theoretical knowledge is more valuable than concrete, practical knowledge.	Predictive theories and universals cannot be found in the study of human affairs. Concrete case knowledge is therefore more valuable than the vain search for predictive theories and universals.
2	One cannot generalise on the basis of an individual case; therefore, the case study cannot contribute to scientific development.	One can often generalise on the basis of a single case, and the case study may be central to scientific development via generalisation as a supplement or alternative to other methods. But formal generalisation is overvalued as a source of scientific development, whereas "the force of example" and transferability are underestimated.
3	The case study is most useful for generating hypotheses; that is, in the first stage of a total research process, while other methods are more suitable for hypothesis testing and theory building.	This misunderstanding derives from the previous misunderstanding that one cannot generalise on the basis of individual cases. And because this misunderstanding has been revised as above, we can now correct the third misunderstanding.
4	The case study contains a bias toward verification, that is, a tendency to confirm the author's preconceived notions.	The case study contains no greater bias toward verification of the author's preconceived notions than other methods of inquiry.
5	It is often difficult to summarise and develop general propositions and theories on the basis of specific case studies.	It is correct that summarising case studies is often difficult, especially concerning the case process. It is less correct as regards case outcomes. The problems in summarising case studies, however, are due more often to the properties of the reality studied than to the case study as a research method. Often it is not desirable to summarise and generalise case studies.

Table 2-6: Five Misunderstandings and Revision of the Case Study (Flyvbjerg, 2006)

Yin (1994) states that the case study is "an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when boundaries between phenomenon and context are not clearly evident". Noor (2008) also adds that the case study is a strategic qualitative research methodology and commonly used in sociology and industrial relations. Table 2-7 shows the advantages and disadvantages of the case study.

Advantages	Disadvantages
• The examination of the data is most often conducted within the context of its use, that is, within the situation in which the activity takes place.	• Case studies are often accused of lack of rigour.
• Variations in terms of intrinsic, instrumental and collective approaches to case studies allow for both quantitative and qualitative analyses of the data.	• Case studies provide very little basis for scientific generalisation since they use a small number of subjects, some conducted with only one subject.
• The detailed qualitative accounts often produced in case studies not only help to explore or describe the data in a real-life environment, but also help to explain the complexities of real-life situations which may not be captured through experimental or survey research.	• Case studies are often labeled as being too long, difficult to conduct and producing a massive amount of documentation.

Table 2-7: Advantages and Disadvantage of Case Study (Zainal, 2007)

Yin (1994) defines three categories of case study, namely: exploratory, descriptive and explanatory. The characteristics of each category are shown in Table 2-8 from which exploratory has been selected for its suitability to qualitative research.

Categories	Characteristics
Exploratory	• To find out what is happening, particularly in little-understood situations. • To seek new insights. • To ask questions. • To assess phenomena in a new light. • To generate ideas and hypotheses for future research. • Almost exclusively of flexible design (qualitative).
Descriptive	• To portray an accurate profile of persons, events or situations. • Requires extensive previous knowledge of situations etc. • To be researched or described, so that the author knows the appropriate aspects on which to gather information. • May be of flexible and/or fixed design (qualitative or quantitative).
Explanatory	• Seeks an explanation of a situation or problem, traditionally, but not necessarily in the form of causal relationships. • To explain patterns relating to the phenomenon being researched. • To identify relationships between aspects of the phenomenon. • May be of flexible and/or fixed design (qualitative or quantitative).

Table 2-8: Categories of the Case Study (Yin, 1994)

The case study for an exploratory research allows the author to generate ideas and questions along with its effectiveness when the research includes complex problem solving activities and processes in great depth (Miguel, 2005). Therefore, the exploratory case study is best suited for qualitative research, i.e. for this research topic. Exploratory is considered as the research starts to investigate, capture and understand the best practices of the A3 thinking as a problem solving approach in product design. The case study research can be adopted for single and multiple-case designs and the details of both designs are represented in Table 2-9.

Single-Case Study	Multiple-case Studies
• Appropriate where it represents a critical case • Extreme and unique case • Revelatory case • Allows to investigate phenomena in depth to provide rich description and understanding	• Allows cross-case analysis and comparison • Investigates a particular phenomenon in diverse settings • To predict similar results or to produce contrasting results for predictable reasons

Table 2-9: Descriptions of Single and Multiple-case Designs (Darke et al., 1998)

The multiple-case study is selected due to its inherent advantages for the perspectives of qualitative research. In addition, the multiple-case study yields more general research findings than a single-case study.

2.2.4 Data Collection Methods

Identification of the methods used to collect data is a very important process in any type of research study as it can address the identified critical research questions and also lead to any invalid results. Yin (1994) states that case studies contain several data collection methods such as questionnaires, interviews, text analysis and direct observations. For this research, the five methods that are appropriately and adequately used to collect data are: 1) literature review, 2) documentation review, 3) direct observation, 4) interview and 5) focus group. During the implementation of these methods, some devices are used such as voice recorder, digital camera, necessary hardcopy of documents, WebEx, emails, telephone calls, and pen and paper. The aforementioned data collection methods are described in the following sub-sections.

2.2.4.1 Literature Review

The literature review is a critical and analytical summary of the findings, from the author's perspective, of the literature search, gathered from primary, secondary and tertiary sources (e.g. journal articles, conference proceedings, books, technical reports and theses). It is one of the important methods for data collection in order to expose the main gaps in knowledge, to build the foundations of the research understanding and also to identify principal areas of the research uncertainty (Mays et al., 2001). The strategy is developed to access the optimal and to write a dissertation on the literature review, for example by identifying the useful databases and keywords, selecting the most relevant findings, and evaluating and analysing the data. In fact, by utilising methods of qualitative research and combining the data analysis from the reviews, bias and error can potentially be reduced (Whittemore and Knafl, 2005). For this research, the internet search engines or open access databases are mainly from Google Scholar, Springer Link, Emerald, Science Direct and EBSCO.

2.2.4.2 Documentation Review

The documentation review is one of the selected data collection methods that refer to written documents such as notices and letters, or non-written documents including diagrams and pictures (Robson, 2011). The sources of the documentation review for this research were divided into two categories: research documents and industrial documents. The research documents consist of the LeanPPD project's proposal, minutes of meetings and memoranda, whilst the industrial documents that needed to be inspected include the following:

- The standard process of product development and design problem solving
- The As-Is practices of problem solving approaches
- The reports and documents of the previously documented design solutions
- Design references and checklists (if any)

All these documents are important for the research data collection as they allow a high level of understanding indirectly, especially in the initial research phase. In addition, the results gathered from the analysis of the review's findings, explained in sub-section 2.2.4.1, alongside these documents could lead to the development of a new A3 template and the opportunities for implementation of the new A3 thinking approach at product design in manufacturing companies.

2.2.4.3 Direct Observation

Direct observation is widely used in qualitative research as a data collection method, having the advantage of directness (Robson, 2011). Direct observation in this research has been applied in several situations such as during industrial meetings and interviews, also industrial visits (e.g. the process of solving design problems). It allows the author to learn and capture the actual things that happen in design problem solving activities in the collaborative company. The collected data from the direct observation method in qualitative research are more powerful and meaningful (Walshe et al., 2012) and provide information obtained visually.

2.2.4.4 Interview

The interview provides verbal data and is used as a common and most frequently used method of data collection (DiCicco-Bloom and Crabtree, 2006; Robson, 2011) and the face-to-face interview is the most versatile method used to collect evidence directly from the person (Bernard, 2011). Brod et al. (2009) state that the purpose of interviews is "to generate new information and confirm or deny known information". This research focuses on semi-structured interviews as a primary data collection method and is based on the stages of developing an interview shown in Figure 2-2 (Wilkinson and Birmingham, 2003).

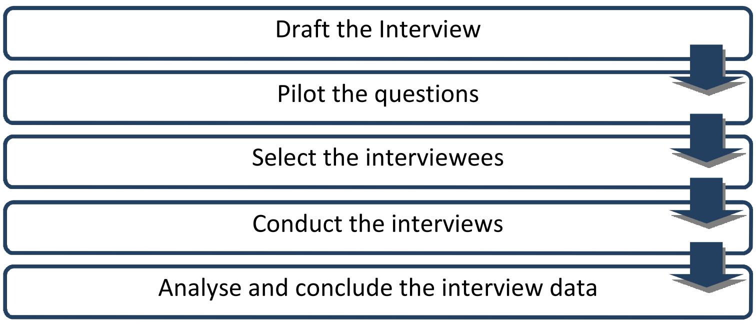


Figure 2-2: Stages in Developing and Using Interviews

During the semi-structured interviews, the author employed the close-ended questionnaire which helped to gain straightforward information within a limited time. By using semi-structured interviews and close-ended questionnaire, rich and in-depth information and feedback from the stakeholders can be captured. The interview focuses on individuals whilst also employing a 'focus group' data collection method for a certain number of people; i.e. a group interview, as explained in the next sub-section. The aim for using these two data collection methods (semi-structured interview and focus group) is explained as follows:

- The semi-structured interview aims to gather data and information individually (one-to-one) for the development of the research foundation, for example to capture the requirements of the new problem solving approach in product design.
- The focus group aims to gather and capture verbal information spontaneously as in a group brainstorming. This is a good data collection method in representing ideas for the new A3 template or reports as an effective communication tool, thus leading to the direct expert judgement by the collaborating company.

2.2.4.5 Focus Group

The focus group arises from the generic term 'group interview' which is designed with specific characteristics, and is a very popular data collection method in many fields of applied social research (Robson, 2011). It helps to identify "a range of experiences and perspectives" whilst the individual interviews offered the opportunity to discover and concur the interaction in depth (Morgan, 1996). Highly influenced by group dynamic behaviour, focus group information is gathered from the thoughts stimulated and prompted by comments from other members (Brod et al., 2009). The focus group is mainly chaired by the author within a small number of stakeholders. Table 2-10 shows the advantages and disadvantages of the focus group. In order to investigate the current design problems and to capture the foundation of a new A3 template, the focus group has been performed a repetitive process. Since the collaborating company is one of the LeanPPD project partners, it is very important to have frequent meetings with the stakeholders in order to ensure the final research findings address the requirements of the project and the collaborating company.

Focus Groups	
Advantages	**Disadvantages**
• Highly efficient method for qualitative data collection • Natural quality controls on data collection operate • Group dynamics help in focusing on the most important topics • Participants tend to enjoy the experience • Inexpensive and flexible • Can express their opinions freely	• The number of questions covered is limited • Facilitating the group process requires considerable expertise • The interview process needs to be well-managed • Conflicts may arise between personalities • Creates a consensus of opinion, rather than idea generation

Table 2-10: Advantages and Disadvantages of Focus Group (Brod et al., 2009)

The focus group is the brainstorming activity, thus the expert judgements could be captured and documented from the collaborating company. This expert judgement from the focus group was captured and explained at sub-section 4.2.2.3 in Chapter 4. Seeking input using an expert panel method, or industrial expert judgement in this research, is a way of reducing the level of bias (Alistair, 2008). This means that it only provides information on some objectives based on a review by the author which is reliable knowledge. In general, expert judgement is a method widely used for content validity fulfilment also as an alternative strategy to ensure content validity from relevant research (Joo and Lee, 2011). This method is used to obtain knowledge about difficult to measure quantities (Kenneth and Nina, 2009). It is a way of reducing the level of bias that can creep in when one relies on a single expert. But, if more than one expert is consulted, the collective judgements result in a form of harmonious opinion. One of the important instruments used to effectively capture the judgements and group brainstorming is a voice recorder which can then be transcribed and analysed. The results will be improved and disseminated amongst the industrial stakeholders.

This section explained the rationale behind research philosophy and the chosen methods providing the best fit for the research. The next section explains the research evaluation that provides trustworthiness and minimises bias.

2.2.5 Trustworthiness and Bias

Trustworthiness is a research value that is one of the effective ways to ensure the quality of the qualitative research (Robson, 2011). There are main threats concerning research validity in empirical studies that can be minimised by the author, categorised under three headings: reactivity, respondent bias and author bias. The latter two are described by Runeson et al. (2003) as follows: The reactivity and respondent bias refers to the risk of the respondent performing differently from usual. For example, during the face-to-face interviews, the respondents might perform in a different way or try to hide information in order to fulfil both the author's expectations and those of the people involved. Author bias is in relation to the assumptions and preconditions that the author may bring to the situation or the selection of certain people through data collection and analysis.

Bias is defined as "a systematic inconsistency in research studies that contaminates a primary comparison and affects the internal validity of the study". It is critical to identify this in research but impossible for it to be totally eliminated (Agabegi and Stern, 2008; Sica, 2006). There are several main strategies for dealing with different threats in order to minimise bias in this research [adapted from (Robson, 2011)] such as prolonged involvement, data triangulation, peer debriefing, audit trail and member checking.

2.3 Research Methodology Adopted

The methodology adopted for the research consists of four phases which are based on the research objectives presented in Chapter 1 and the key tasks and deliverables in order to draw out the research, as shown in Table 2-11.

Phases	Key Tasks	Deliverables
1. Synthesise the A3 thinking best practices	1.1 Literature review 1.2 Documentation review	A3 best practice identification
2. Evaluate problem solving approaches and their impact in product design	2.1 Inter-relation analysis 2.2 Knowledge management capability levels analysis 2.3 Direct observation 2.4 Semi-structured interview 2.5 Focus group	A new A3 template
3. Develop the A3 thinking approach	3.1 Utilising LAMDA learning cycle in new approach 3.2 Developing a new A3 template 3.3 Adopting the reflection questions of What-So what-Now what 3.4 Generating the process of using the A3 Thinking Approach 3.5 Develop the new A3 template in Microsoft Word Developer	A novel A3 Thinking Approach
4. Validate the A3 thinking approach	4.1 Industrial case studies 4.2 Industrial expert judgements 4.3 Industrial LeanPPD workshops	Validated approach

Table 2-11: Research Methodology Formation

The following describes the key tasks for each phase in the research methodology.

Key Task 1: Synthesise the A3 thinking best practices

1.1 a. A literature review was performed to synthesise a lean thinking application to enhance the understanding and contribution to support LeanPPD.

b. Perform state of the art review of problem solving approaches and investigate the influences as well as the lean application for problem solving.

1.2 Identify the current problem solving practices and knowledge capturing, and share challenges by reviewing and analysing the related documents collected from the collaborating company.

Key Task 2: Evaluate problem solving approaches and their impact on product design

2.1 a. Appreciate the inter-relation analysis among the different problem solving approaches captured from the literature and documentation reviews on A3 best practice identification (results from Key Task 1).

b. Understand and capture the new elements for a new A3 template through the results from the inter-relation analysis and semi-structured interviews.

2.2 a. Identify the knowledge management capability by reviewing the latest issues and challenges in organisational knowledge management from the literature review.

b. Analyse the problem solving approaches by considering identified knowledge management capability of creation, capture and sharing to aid the generation of knowledge driven design. For this research, this analysis is called Knowledge Management Capability Levels Analysis.

2.3 Capture and analyse the actual processes/methods/challenges in design problem solving through direct observation in the collaborative company during industrial meetings and interviews, also industrial visits.

Key Task 3: Develop the A3 Thinking Approach

3.1 Design a new A3 template and generate the process for the A3 thinking approach that will enhance the knowledge provision based on the results from the semi-structured interviews, direct observation and focus group.

3.2 Develop the A3 thinking approach that will be formulated based on the results of the above key tasks by:

- Utilising the LAMDA learning cycle in a new A3 thinking approach
- Developing a new A3 template
- Adopting the reflection based on questions of What, So what and Now what
- Generating the process of using the A3 thinking approach based on the new A3 template

- Develop the new A3 template in Microsoft Word Developer as an alternative for designers to apply it

Key Task 4: Validate the A3 Thinking Approach

4.1 Validate the A3 thinking approach through industrial case studies for the automotive sector.

4.2 Validate the A3 thinking approach through industrial experts' judgements during focus groups and case studies.

4.3 Validate the A3 thinking approach with experts who never associated with the research through LeanPPD industrial workshops.

2.4 Chapter Summary

This chapter explained the origins, rationale and various associated issues in qualitative research by focusing on selected research and data collection methods. The research methodology adopted has clearly described each phase and process as illustrated in-depth in the flow diagram. Each of these phases was covered based on research objectives including; synthesise the best A3 thinking practice, evaluate the problem solving approaches and their impact in product design, develop and validate the A3 thinking approach. The following chapter presents the review and analysis of the problem solving approaches.

Chapter 3

3 REVIEW AND ANALYSIS OF PROBLEM SOLVING APPROACHES

3.1 Introduction

This chapter reviews and analyses problem solving approaches to support lean product and process development, as outlined in Figure 3-1. Section 3.2 focuses on the overview of lean product development specific to the research area at the initial phase in product development – product design. In this section, the definition of the key stages in the design process is presented and the fundamentals of lean thinking are explained. Section 3.3 explains the problem solving approach for product design; whilst the inter-relation analysis among problem solving approaches is presented. The learning cycles for product design and the appropriate learning cycle for the A3 thinking approach is finalised, based on the expected criteria to support knowledge creation. Section 3.4 describes the knowledge management capabilities to support knowledge driven design. These capabilities were identified based on the evolving issues and challenges in managing organisational knowledge. The analysis, by considering the knowledge management capabilities of creation, capture and sharing, led this research to identify the limitations of the problem solving approaches to support knowledge driven design within a LeanPPD environment and presented in Section 3.5. The research gaps are identified and summarised in Section 3.6 and finally, the chapter summary is given in Section 3.7.

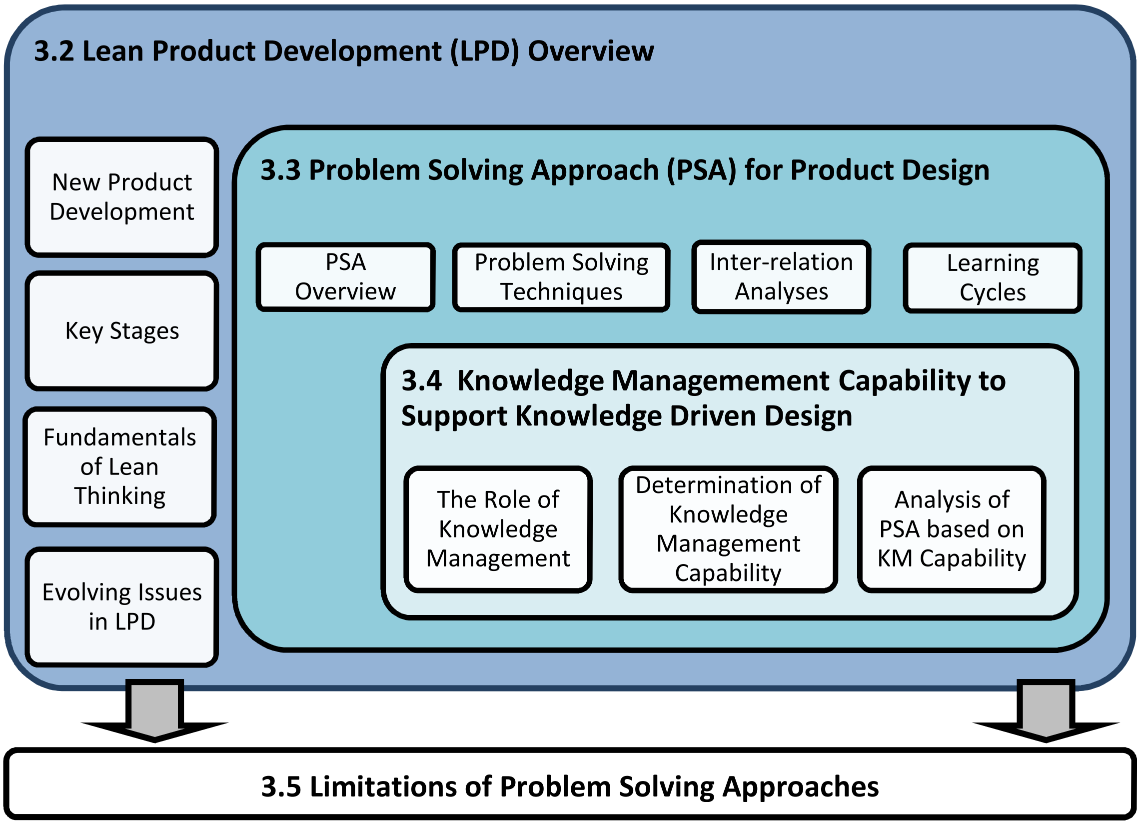


Figure 3-1: Main Topics of Chapter 3

3.2 Lean Product Development: An Overview

3.2.1 New Product Development

Today's climate of globalisation has dramatically affected most companies, from the smallest to the largest multinational, in developing and manufacturing products. New product development (NPD) is an important commitment in manufacturing companies. It is an interdisciplinary and creative activity to ensure that the company offers a wide variety of products in order to satisfy customer demands (Krishnapillai and Zeid, 2006). NPD involves important activities such as product specification, product design and engineering, production planning, manufacturing and assembly and also purchasing and commercialisation, as shown in Figure 3-2. This figure shows the NPD cycle from obtaining market and customer needs until the provision of the product. But the product design and engineering is at the centre of the product life-cycle since all the needs are developed from the specific designs. The research area also focuses more precisely on product design at the initial stages of the product development.

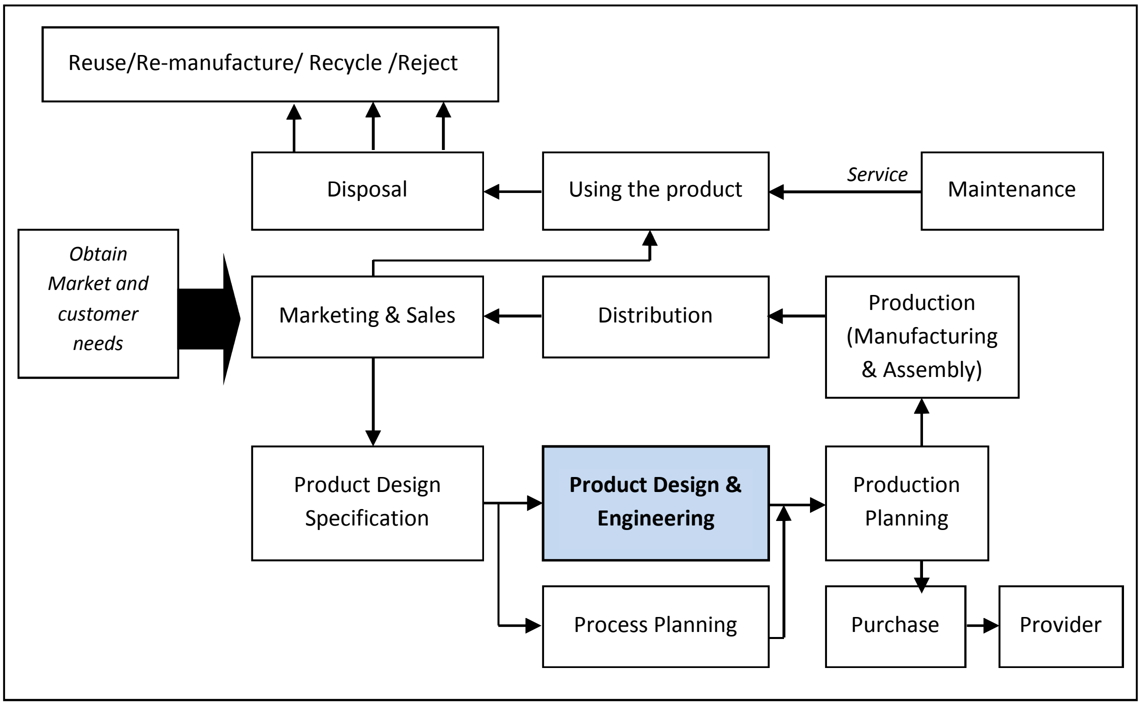


Figure 3-2: New Product Development Cycle

Theoretically, NPD is not enough by itself to make a successful product but can assist in the creation of the product that helps the company to succeed in the global economy (Kono and Lynn, 2007). However, the constant changes in the global economy and continuous demands from the market compel the company to make decisions concerning the development of new products. The manufacturing company that fails to make correct decisions in the initial phase will increase of the life-cycle cost in product development up to 75%-80% (Yan Li et al., 2007; McCarthy et al., 2006; Mileham et al., 1993). Thus, the activities in NPD are critical and will provide continuous support to manufacturing companies, involving all divisions, processes and tools. However, determining the core processes in product development and defining the relationship to the company's capability are vital for sustainable success in developing a new product (Liu, 2003). In addition, making the right decision at the initial process in product development will minimise the potential risks; this decision must be supported by a proper set of knowledge requirements. The design engineers are also able to bridge the gap between market conceptualization and the realities of production (Hong et al., 2005).

The primary contribution of this research will be visualisation of the useful knowledge that will be obtained from the problem solving activity. For this reason, this research will focus more on a 'root' process in the product development – product design. In product design, the problem solving activity is vital and will facilitate the elimination of potential defects and risk factors for the next process in product development. Thus, every stage involved in the product design process needs to be described separately. The following section will introduce and define the key stages in product design.

3.2.2 Key Stages in Product Design

The product design process has the goal of defining and producing a product to fulfil a set of requirements (Clarkson and Eckert, 2005). The activity in the product design process is very important, where designers must identify the characteristics and properties of the products (Cross, 2000). Communication between the engineers or designers and the team and customer is even more important. This is to evoke continuous feedback as the products become more complex with the latest developments in science and technology.

The product design process includes a series of stages and check-points at which each step can be reviewed and analysed. It is usually a process where each of the key stages must overlap one another in order to ensure the final design or product fulfills the requirements (Brissaud et al., 2003). In the product design process (as described below) there are four main stages: (1) requirements (2) conceptual design, (3) embodiment design and (4) detailed design. The first stage begins with the clarification activities from customer needs which involve the collection of information regarding the design requirements and also existing constraints and their consequences (Wynn, 2007). Basically, in the design task, major tools such as Quality Functional Deployment (QFD) are used to translate a customer's requirements. This is to avoid the designers facing the problem of identifying the market needs by dealing with explicit requirements (Pahl et al., 2007). The activities in the first stage of the product design process enable a detailed understanding of the design problem or requirement to be obtained and the formulation of the information using a product design specification (PDS). The PDS is an element used to define concisely all the characteristics of the end product and also provides a safeguard for designers to change the original requirements.

The conceptual design is an important stage in the design process for generating a concept and attempts to actively make improvements based on the formulation in PDS whilst generating the concept. The concept is an idea gathered from understanding the primary problem and requirements. This is to 'measure' the problems from a physical standpoint, and to accordingly evaluate the design proposal. During the conceptual design phase, the determination and establishment of a set of principles for function structures and a combination of concept variants will be developed. At this stage, the unforeseen nature of creativity is difficult to apply effectively (Mulet and Vidal, 2008). Several tools exist, such as morphological charts, tree diagrams and axiomatic designs, which can be used for concept generation and selection. The final concepts will represent the physical principles to solve a problem (Wynn, 2007) but may possibly have several actual solutions. The variants that do not satisfy the requirements need to be eliminated (Cross, 2000). At the conceptual phase, the final result is the concept design drawing. Though the embodiment design is abstract, the conceptual design path and decisions during this phase must be justified by physical proof. In this phase, the final concept will be transformed to the design layout (Pugh, 1991). Most importantly, the embodiment design phase must elaborate on the design documents, such as drawing and appropriate parts lists, using Computer Aided Design (CAD) software. The final phase is the detailed design that refers to design documentation and presentation and leads to the expression of the product architecture (Pahl et al., 2007). Here, the final decisions in the design process will be released for manufacturing preparation. All the dimensions, tolerances, precise shapes and material selection will be defined at this stage. Most importantly, conceptual design and embodiment design must overlap with at detail design in order to ensure that the final product meets the desired requirements within its specification. This is to avoid iterations of the product design process (Wallace and Clarkson, 1999).

According to the definition of the key stages, product design is shown as the most crucial process in product development for three reasons: 1) the results at all stages must overlap and complement each other, 2) the product design process will involve more than one designer so the combination of the experience of and interaction with other designers for all the key stages will generate discussion among them, and 3) communication between designers and manufacturing engineers must be very useful for both sides in order to prevent any problems. For example, if the manufacturing engineers identify a flaw in the design drawing, the possibility of designers needing to redesign the concept is higher. In order to overcome this, lean thinking has been proposed. Therefore, this research aims to support decision making and communication hence to reduce mistakes. Despite the remarkable achievements of applying lean thinking in manufacturing shop-floor, the following section will describe the fundamentals of lean thinking for the product development.

3.2.3 Fundamentals of Lean Thinking

The word 'Lean' is based on the Toyota Production System (TPS) which was originated by Taiichi Ohno, of Japanese Toyota Development. After several decades, Toyota has developed their TPS as a lean system in manufacturing. It is successfully applied to managing manufacturing companies, considering any activities that create value and eliminate waste (Haque and James-moore, 2004). Lean thinking is a way to provide skills and a shared means of thinking to design in a systematic and better way. It also provides opportunities to improve production time and costs, and in addition, production efficiency (Van-Der Krogt et al., 2009). The originality of lean thinking starts on the shop-floor of Japanese manufacturers and imposes domestic competition in Japan mainly for car makers. From the 1950s to the 1970s, Toyota completely applied lean to car manufacturing, vehicle assembly and the supply chain. After that, the 'hidden' secret behind Toyota was shared for the first time with other companies outside Japan. This opportunity was largely driven by western manufacturing to compete with Toyota's performance until the book entitled 'The Machine that Changed the World' highlighted the various gaps between western and Toyota performances (Hines et al., 2004). They stated that the lack of contingency was the first criticism of lean in less efficient manufacturers. This is because manufacturers focus on lean on the shop-floor and rely on the five lean principles but not on lean integrative approaches. However, the key to the high performance of Toyota is the fact that they practise a continuous improvement and learning culture within their underlying lean principles (McManus et al., 2007).

The lean principles that are proposed by Womack et al. (2007) are highlighted as: (1) specify value; (2) identify the value stream and eliminate waste; (3) create the value flow; (4) let the customer pull the processes; and (5) pursue perfection. These principles are summarised in Womack and Jones' statement about 'lean thinking', i.e. that it "provides a way to specify value, line up value-creating actions in the best sequence, conduct these activities in the best sequence, conduct these activities without interruptions whenever someone requests them, and perform them more and more effectively" (Womack et al., 2007). All these principles are commonly applied to the shop-floor (or called lean manufacturing) and lean enterprise.

The transformation of lean tools and techniques on companies' shop-floors has changed the landscape of the traditional environment. This transformation has allowed organisations to work more smartly with quantum improvements and has driven growth of the manufacturing companies with marginal benefits (Oosterwal, 2010). But to be more effective, and for manufacturing companies to be more efficient, lean thinking cannot stop at the shop-floor. The shop-floor constitutes only one chapter in lean thinking and companies almost never form a true learning culture in their process – lean manufacturing and lean enterprise represent limited and piecemeal approaches (Liker and Morgan, 2006). Figure 3-3 shows a classification of lean thinking application as lean manufacturing, lean enterprise and lean product development. Referring to the above reviews, initially, lean is a better way to approach the changing product market and is composed of principles that provide manufacturing with the foundation for a manufacturing revolution that would meet the market challenges. Thus, lean product development is a clear advancement for lean manufacturing and lean enterprise. The key principle of lean application in lean product development is empowerment of the employees. However, this can only be achieved through extensive engagement in decision making, problem solving and continuous improvement (Vidal, 2007; Womack et al., 2007). This has motivated the author to develop a new approach to support lean application for problem solving in product development. However, lean product development is new and still in its infancy. This can be verified from the lean practitioners' statements in the next sub-section.

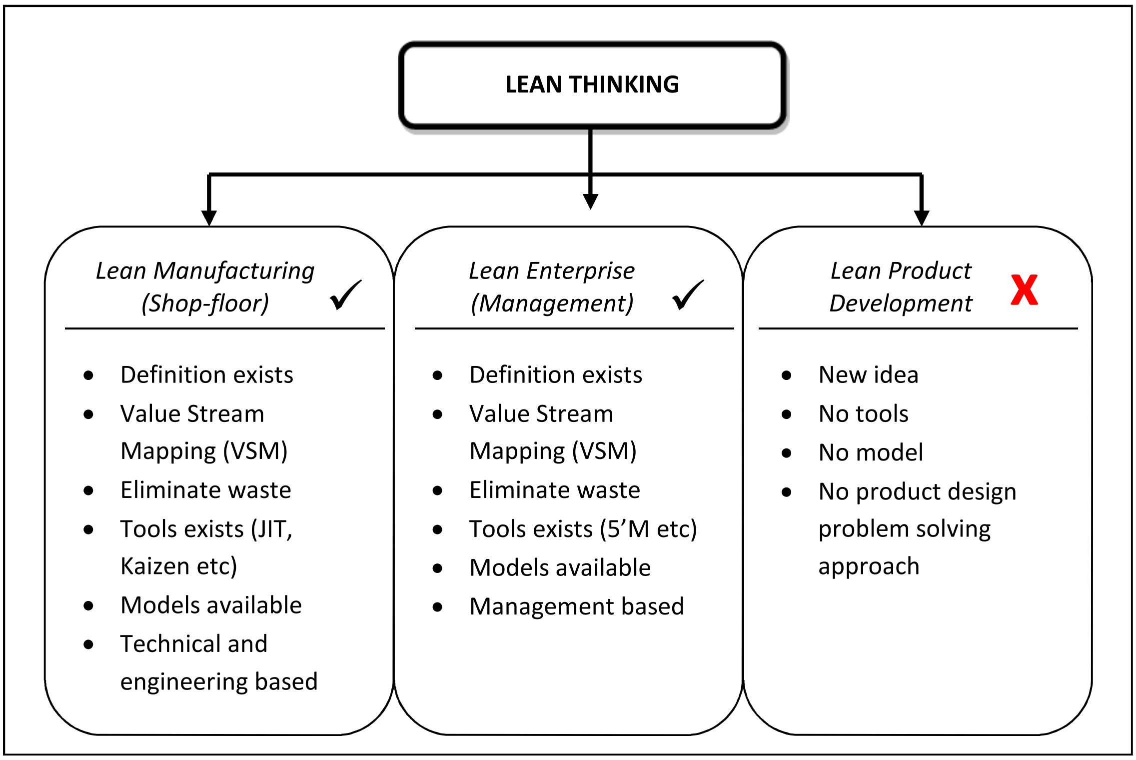


Figure 3-3: Classification of Lean Thinking

3.2.4 Evolving Issues in Lean Product Development

The importance of the application of lean in product development has been established in the literature. Some authors also suggest that there is still a need to improve lean product development by using empirical data and experience-based techniques, rather than being based only on theoretical assumptions. The following describes the issues in lean product development.

a) Bauch (2004) explains that there are still large gaps in knowledge to apply lean in product development.
b) Liker and Morgan (2006) refer to the complexity of human systems and technology, making the need for systematic perspectives more critical to the 'lean initiative' in product development.
c) According to Ward (2007) "Almost all defective projects (projects that miss the market, have manufacturing cost or quality problems, or budget and time overruns) result from not having the right knowledge in the right place at the right time. Therefore, re-useable knowledge is the basic value created during development. Re-useable knowledge prevents defects, excites customers, and creates a profitable operational value stream which is the goal of product development." However, Ward only explains and gives advice on general views of the application of lean in product and process development by transition to a new concept of good strategy. In his book, he neither explains the detailed process in product development and process, nor structures a detailed model of applying lean in product development. Thus, the book does not apply lean to actual scenarios for the process and development of product.
d) Hoppman (2009) claims that shortcomings of existing approaches in the introduction of lean product development (Fiore, 2005; Kennedy et al., 2008; Liker and Morgan, 2006; Schulze and Störmer, 2012; Ward, 2007) remain unclear and are open to argument. All these publications are not based on empirical data but more on the theoretical 'expectation' between the lean principles. Hoppman (2009) also suggests that experience-based information can be the best review for applying lean thinking in product development.
e) Hoppmann et al. (2009) also introduce from Hoppman's previous study, the application of lean in product development using quantitative data, collected from 910 product development managers, product engineers and chief

engineers of international companies. Unfortunately, they did not clearly define the critical activities and major processes in product development.

f) Oosterwal (2010) provides the most statistical results based on a study in the Harley-Davidson Motorcycles Company. These results include an increase in new product output, elimination of launch issues and problems late in the development cycle. However, the case study is subject to bias and requires academic analysis to verify the results and causality. The case study, if accepted, represents a single product type from the automotive sector (Khan et al., 2011).

According to the issues identified in lean product development, the opportunity is open for the research to be taken further. This research provides a more experience-based analysis that generates empirical data, also focusing more on the critical phase in product development. Liker and Morgan (2006) provided thirteen principles for lean product development (Lean PD) as shown in Figure 3-4 as a foundation for practitioners and these are divided into three major frameworks: process, people and tool or technology. These frameworks are established in order to prevent confusion and continuous mistakes with regard to lean application in different areas.

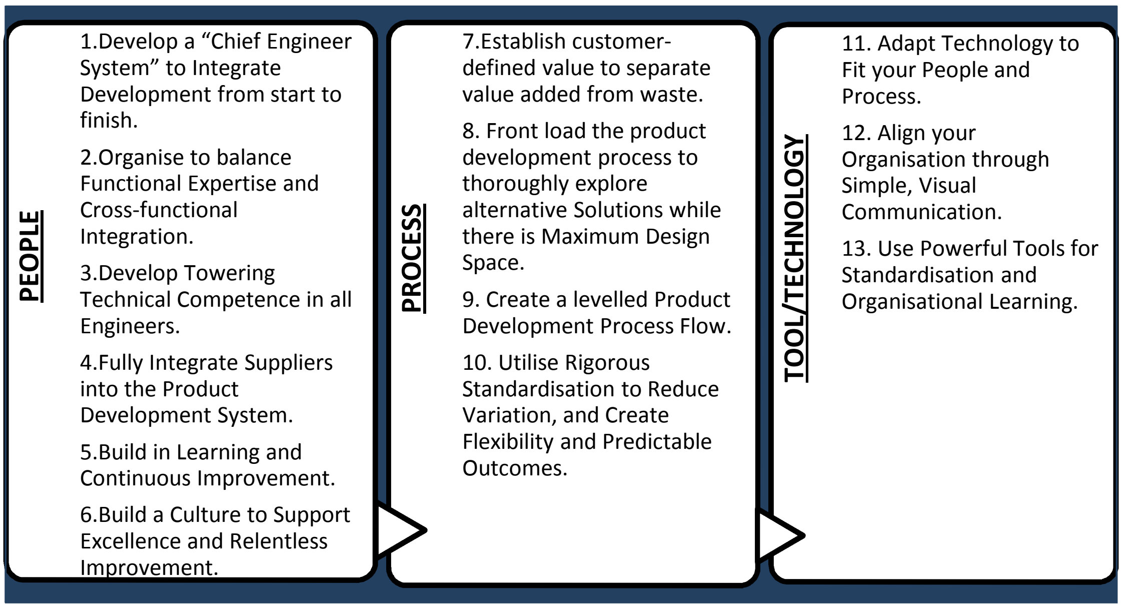


Figure 3-4: Lean PD Principles (Liker and Morgan, 2006)

Lean product development needs the provision of knowledge to support critical activity such as problem solving, especially in decision making where it has major influences on manufacturing cost and production lead time. This activity will generate knowledge that is important to the rest of the product development as well as any future projects. The issue is how to provide a novel approach, a new way of thinking for designers and engineers, to support this activity of solving problems to create a new knowledge-rich environment in product development in order to support decision making and hence to reduce design mistakes. Research into the issues involved in product development has opened the way towards a new approach to support LeanPPD.

Since this research focuses on problem solving in product design, the next section describes the problem solving approaches for the best practice of the new A3 thinking approach by considering the relation to knowledge such as: What is the best approach of problem solving in product design?; How can the problem solving approaches create and deliver the knowledge effectively and adequately?; and finally, What is the process or necessary elements for a new A3 template that can contribute to knowledge? By addressing these questions, the A3 thinking approach could be developed to support knowledge driven design.

3.3 Problem Solving Approach for Product Design

3.3.1 Problem Solving Approach Overview

Problem solving is a mental process which starts with discovering the problem, determining the best possible action to take in a given situation, proceeding to analyse it hence to provide and verify the solution (Mohd Saad et al., 2012(b)). Solving problems in product design is a complex activity comprising a number of alternative techniques (Chandrasekaran, 1990). Many difficulties in the design process appear during this activity because people may be rushing to solve the problem without scientific knowledge. Scientific knowledge is a basic value to prevent design flaws, produce higher quality designs and also create profit for the company. The previous section explained each stage in product design where the design process is the most crucial process that produces design flaws, hence increasing life-cycle cost in product development. These issues can be prevented by using an effective problem solving approach in order to help eliminate such issues in the product design.

An enormous range of approaches to problem solving exists. The following explains some problem solving approaches that have been or could be used in product design; **Brainstorming (BS)** allows the designers to discuss and explore potential ideas to solve a problem hence, to represent and verbalise their arguments spontaneously (Amir-Abbas and Reza, 2012). **Theory of inventive problem solving (TRIZ)** is derived from the study of the patterns of problems and solutions (Li et al., 2007; Hua et al., 2006). **8 Disciplines** (8D) is for solving problems in product and process improvement which are recurring (Zareba et al., 2011) and to generate possible solutions for product requirements, conceptual, detail design, and prototyping (Hua et al., 2006). **A3 Report** is created from the A3 template, and has been used as a problem solving and effective communication approach in manufacturing and management (Shook, 2009; Shook, 2008; Sobek and Smalley, 2008; Ghosh and Sobek, 2006; Jimmerson, 2005). It follows evidence and logical structures of the seven elements in sequence, which are separately allocated on the A3 paper based on the Plan-Do-Check-Act (PDCA) learning cycle (Kimsey, 2010). **Creative Problem Solving (CPS)** is used to create new ideas for products (Wu et al., 2006) and to enhance the creative thinking of the design team (Lim et al., 2010). **Kepner-Tregoe (KT)** is associated with states shifting from As-If to To-Be (Wu et al., 2010) which consists of two main stages: problem analysis and decision making (Zareba et al., 2011). **5 Whys** is to identify the root cause of a problem (ask 'why' five times) (Sproull, 2001) and use in manufacturing operations which provides a fact based and structured approach to addressing the problem, reducing and eliminating the defects (Murugaiah et al., 2009). Fantoni et al. (2006) state that 5 Whys is commonly used at the first stage in the design process for design requirements and customer value identifications. **Root cause analysis (RCA)** is designed to investigate and identify the origin of the problems along with fixing them. It is significant in improving the product quality and process productivity whilst controlling variations during the manufacturing process (Marapoulos and Ceglarek, 2010). Doggett (2005) states that RCA is has also been used for possible issues in design stages and well-identified causal relationships. **Problem Analysis Flowchart (PAF)** uses a single sheet and its advantage is that an inexperienced person will be able to understand clearly how to solve a similar problem by looking at the provided template (Sproull, 2001).

The potential of five problem solving approaches (5 Whys, RCA, PAF, 8D and A3 report) were examined by the author. The reasons for selecting the approaches are because the full problem solving processes are provided by two approaches, namely 8D and A3 report and applied in product design i.e. 5 Whys, RCA and PAF. Moreover, all these approaches are non-statistical or computational and were developed by utilising a template. The template has become the most preferred method in European manufacturing companies as a mechanism to capture and document knowledge (Mohd Saad et al., 2012(a)). The non-selected approaches (BS, TRIZ, CPS and KT) could be considered as tools for particular processes in the new A3 thinking approach. The five selected approaches are explained in detail in the following subsections.

3.3.1.1 5 Whys

One of the familiar approaches used to identify problem root causes is the 5 Whys approach (i.e. ask why five times). Originally it was implemented in the analysis phase of the Six Sigma roadmap which is more focused on quality control (Sproull, 2001). It is one of the iterations and simple solution techniques which do not require data collection plans. Also, it helps the problem solver to find the root of the problem quickly by using a 5 Whys template (Appendix 1) and fishbone diagram (iSixSigma, 2010). The fishbone diagram or Ishikawa diagram shown in Figure 3-5 was popularised by Kaoru Ishikawa in the 1960s and is one of the seven basic tools of quality management. The Ishikawa diagram is divided into two sections: effect, or problem, and cause. The cause section is to determine the root cause of the problem by using the 5 Whys approach at each cause category. The common categories of cause are presented in Figure 3-5 including method, environment, people, material, machine and measurement. 5 Whys is strongly used in the first stage in the design process for design requirements and customer value identification (Fantoni et al., 2006). The 5 Whys approach is also implemented in manufacturing operations (Murugaiah et al., 2009) which provide possible solutions to reduce non-value adding activity. From their case study, the 5 Whys analysis provides a fact-based and structured approach to address the problem, not only reducing but eliminating defects. They successfully applied the 5 Whys approach to reduce scrap losses in a lean manufacturing environment. As a consequence, this zero cost solution approach could be implemented in order to reduce waste or defects. Figure 3-6 shows the procedures for applying 5 Whys analysis to identify problem root causes.

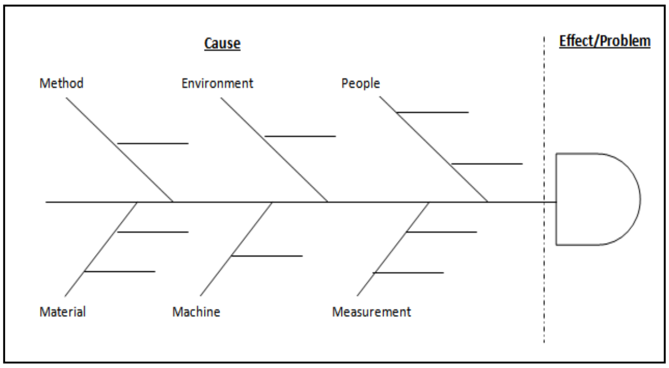


Figure 3-5: Fishbone Diagram (iSixSigma, 2010)

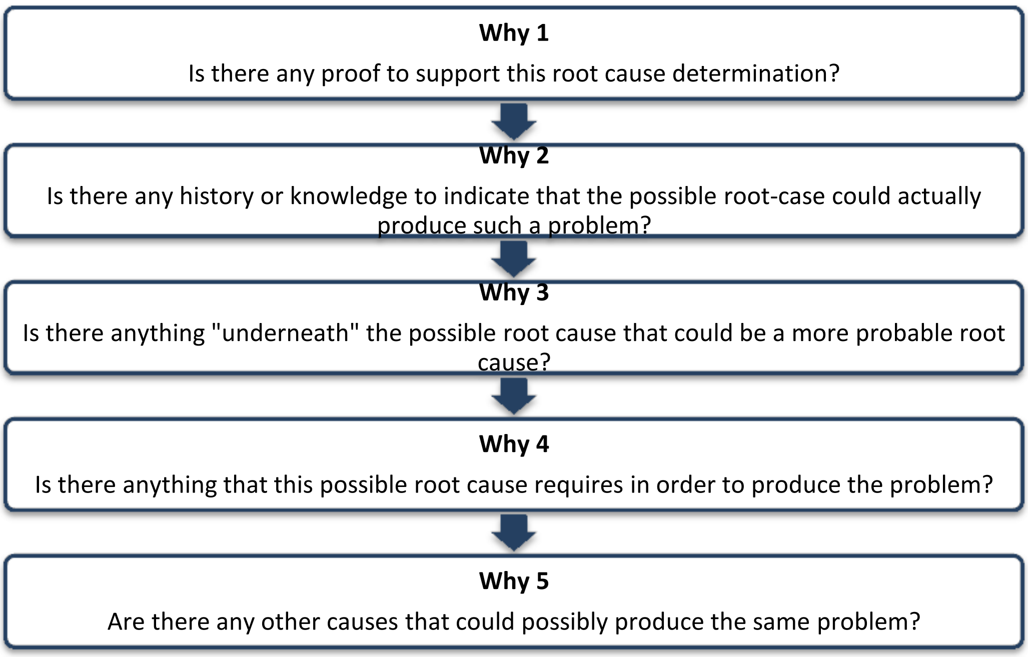


Figure 3-6: 5 Whys Root Cause Identification (IMS Inter., 2010)

According to the literature review, the research has identified the implementation of the 5 Whys approach in product design to identify design requirements or problems, but there is no knowledge creation in this approach. This is because the process of the 5 Whys (asking 'why' five times) only facilitates designers to think and develop the reasons for the causes but the solutions are not detailed, explained or verified.

3.3.1.2 Root Cause Analysis

Root Cause Analysis (RCA) is an approach to investigate and identify the origin of problems. Problems that have been successfully solved include accidents, quality issues, human errors, maintenance problems, medical mistakes, sentinel events, productivity issues, manufacturing mistakes and production delays (Taproot, 2007). Kim et al., (2009) also state that the application of RCA in critical events in aviation accidents and incidents in aerospace companies is increasingly interesting due to the capability of RCA to address disruption. Marapoulos and Ceglarek (2010) state that RCA is critical to improve product quality and process productivity while controlling variations during the manufacturing process. Magniez et al. (2009) highlight the RCA information as enhancing the level of understanding of failures either by the manufacturing process, the design stage, environmental conditions, or the user profile.

The objective for the RCA and 5 Whys approaches is the same, i.e. to identify the root cause of the problem; the presentation of the solutions is similar, where RCA also can be illustrated using the fishbone diagram or using an RCA template (Appendix 2). The root cause of the problems using RCA is obtained by following a 'few steps' sequence as in Table 3-1. According to the explanation of the RCA steps sequence, there is dissimilarity between RCA and 5 Whys approaches. The difference is that 5 Whys determine the root causes by asking why five times as a step process, with no data collection required or any knowledge creation. While in RCA, the determination of root causes is the secondary goal of prevention, but more importantly it is to identify the effective solutions (IMS Inter., 2010). Based on the RCA's template, the issue, root cause and possible solution are easily identified. These will help designers and problem solvers to prevent and/or fix possible issues.

Steps	Key Task
1. Define the problem	• What do you see happening? • What are the specific symptoms?
2. Collect the data	• What proof do you have that the problem exists? • How long has the problem existed? • What is the impact of the problem?
3. Identify Possible Causal Factors	• What sequence of events leads to the problem? • What conditions allow the problem to occur? What other problems surround the occurrence of the central problem?
4. Identify the root cause(s)	• Why does the causal factor exist? • What is the real reason the problem occurred?
5. Recommend and Implement Solutions	• What can you do to prevent the problem from happening again? • How will the solution be implemented? • Who will be responsible for it? • What are the risks of implementing the solution?

Table 3-1: RCA Steps Sequence (MindTools, 2010)

The RCA can lead to knowledge creation where all the data and information in the RCA's template can be referred to and be well-structured to prevent any possible issues for the next project. A well-structured presentation and documentation after solving a problem is very important as some of the narrative-style reports make it difficult for problem solvers to understand and to identify the interactions between the causes and effects of the problem. This is because these interactions are very complex, not well-defined and structured especially for complicated issues (Kim et al., 2009).

3.3.1.3 Problem Analysis Flowchart

The problem analysis flowchart (PAF) is a single sheet problem solving device that includes boxes as shown in Appendix 3. It contains ten major steps and is numbered sequentially to guide the order of completion, namely: 1) problem statement, 2) symptoms, 3) changes, 4) relevant data, 5) defect free configuration, 6) distinction, 7) causal chains, 8) test, corrections, result and conclusion, 9) most probable cause and 10) short term and long term corrections and controls. This approach has been applied in a few case studies in manufacturing processes such as productivity in production, tripping overload and high-pressure faults. All these problems required continuous observation in the manufacturing process since the process solution required performing the test and validating the corrections several times (Sproull, 2001). All these steps are explained in Table 3-2.

Step	Details
Problem Statement	Considering two different perspectives which are the object and defect. The object will be a process, machine, part and system. The problem statement will ask what, where, when, scope and trend.
Symptoms	Symptoms are faults that need to be observed. This step includes faults, signs of problems.
Changes	The change might have occurred prior to the onset of the problem.
Relevant data	Any relevant information or data that can help to resolve the problem.
Defect free configurations	Helps to eliminate potential problem causes.
Distinction	Always compare the process or object with the problem to the process or object without the problem, not vice versa.
Causal chains	Causal chains are the logical steps from symptoms to the cause of the problem. Each step is the cause of the next step and the effect of the previous one.
Test, corrections, results and conclusion	All these activities will eliminate potential root causes.
Most probable cause	Review all the analysis and discuss the results by listing the underlying causes of the problem.
Short term and long term corrections and controls	The short term action – requires little effort and the problem is fixed on the spot. The long term action – requires more effort and the problem is continuously improved.

Table 3-2: Detailed Steps in the PAF (Sproull, 2001)

The research found all the test and corrections results are analysed and concluded in the causal chains box. This causal chain is a conclusion and future reference for possible similar problems. The advantage is that the inexperienced person who looks at the PAF will clearly understand the direction to be taken to solve a similar problem. According to the steps in the PAF template as shown in Table 3-2, the research identified this approach is not suitable for the product design process, since the investigation and determination of the root cause is achieved by conducting several test and corrections. As a consequence, the repetition tests and corrections will affect production lead-time and cost. This process also seems like a 'trial-and-error' solution within the causal chain. The causal chain is only the solution to structures and documents during the root cause analysis.

3.3.1.4 8 Disciplines

The 8 Disciplines (8D) was first popularised in the 1960s and 1970s by the Ford Motor Company (Hawker, 2008) and is also termed Team-Oriented Problem Solving (TOPS) (Kamsu et al., 2008). It is a formal and disciplined approach to solving complex problems which uses a combination of effective techniques and tools (QAI, 2010). The reason for naming this approach 8D was the fact that it is structured on an 8D template by eight disciplines, namely: 1) form the team pitfalls, 2) clarify the problem, 3) contain the problem pitfalls, 4) identify the root cause, 5) generate solutions, 6) implement permanent solution, 7) prevent recurrence and 8) congratulate the team.

In the design process, the fifth discipline of 8D has been used to generate possible solutions for product requirements, conceptual and detailed design, and prototyping (Hua et al., 2006). Behrens et al., (2007) state that the fourth and fifth disciplines in 8D are to close the gap in the complaint management of suppliers at different levels of the supply chain. The idea is to decrease misunderstandings and loss of information during the data exchange between enterprises. The 8D will lead to the discovery of the root causes and possible solutions with consideration of cost, timing, effect on customers, quality, cost reduction and the impact on the organisation. Table 3-3 shows the details of the 8D approach to solving a problem, while in the 8D template (Appendix 4) the solutions are represented using charts, diagrams and open-ended questions.

Discipline	Detail
1. Form the team pitfalls	Identify the team that should be involved such as containment, analysis and solve a problem.
2. Clarify the problem	Clarify the problem highlighted by customer. Should be cleared about current situation and problem background.
3. Contain the problem pitfalls	Provide customer from intermediate problems until permanent corrective action is implemented.
4. Identify the root cause pitfalls	Identify any potential of causes and try to eliminate the root cause.
5. Generate Solutions	Analyse the solution and confirm the correction action will solve the problem.
6. Implement permanent solutions	Implement the corrective action and control or monitor the potential effect.
7. Prevent recurrence	Modify and control the performance to prevent the same problem.
8. Congratulate the team (Validation)	Recognise the teamwork and their efforts. Solve the problem and share the knowledge.

Table 3-3: 8 Disciplines of Problem Solving Approach (Arnott, 2004)

3.3.1.5 A3 Report

The A3 report (hereafter referred to as the traditional A3 report to differentiate it from the new A3 template presented in Chapter 5) started to be written in the 1960s and is a technique that the Toyota Motor Corporation uses to propose any possible solutions. It successfully generates a concrete structure to address problems. “The A3 report is a mechanism to foster deep learning, engaging collaboration, and thoroughness” (Sobek and Smalley, 2008). Ideally, A3 paper is a communication tool that follows evidence and logical structures (Kimsey, 2010). The traditional A3 report, as a good visualisation method (Lindlöf et al., 2012), is usually represented as having 4 minor variations: proposal, problem solving, status reporting and competitive analysis (Liker and Morgan, 2006). As a systematic approach for problem solving on a single piece of A3 paper, the ultimate goal is not only to solve the problem and to be an effective communication tool, but also to make the process transparent and comprehensible in a manner that creates ‘full on’ thinking and learning (Ghosh and Sobek, 2006; Jimmerson et al., 2005; Shook, 2009; Sobek and Smalley, 2008). The traditional A3 report helps to gain a deeper understanding of the problem and opportunity, and guides the way to address the problem. As with the A3 report system in Toyota, the traditional A3 report is a way to cultivate the intellectual development of its peers (Sobek and Smalley, 2008).

There are three advantages of the traditional A3 report: (1) the format requires conciseness and focus; (2) traditional A3 report writers learn quickly by using pictures and other visuals to maximise the information to fit on a report; and (3) all of the important information stays at the front – unlike slide presentations during the discussion (Whittier Inc., 2005). Figure 3-7 presents the traditional A3 template by using a single piece of A3 sized paper, and includes the seven elements starting with background and continuing with current condition, future goal, root cause analysis, countermeasures, implementation plan and follow-up action, separately allocated on two sides of A3 paper based on the Plan-Do-Check-Act (PDCA) learning cycle (Kimsey, 2010).

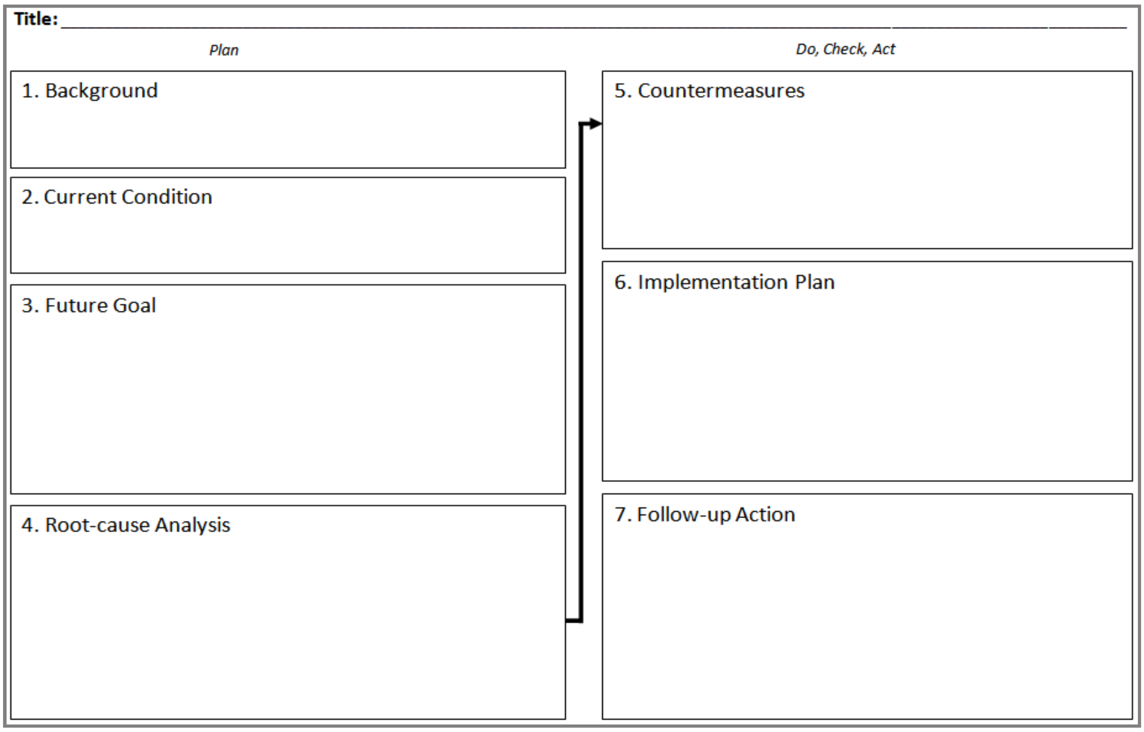


Figure 3-7: The Traditional A3 Template (Sobek and Smalley, 2008)

The PDCA learning cycle is placed at the top of the template in order to guide and encourage the problem solvers for continuous improvement. Aloini et al. (2011) state that continuous improvement is open to different interpretations: it can be considered as (a) a set of exercises and processes that give rise to a continuous innovative flow, which motivates the entire organisation towards sustainable excellence, and also as (b) a set of competitive aptitudes that encourage organisations to learn, innovate and renew. Hence, the acronym of the PDCA learning cycle should be focused on Aloini et al. (2011)'s definition. It could be argued, however, that the way the PDCA learning cycle is fixed on the traditional A3 template can encourage designers to utilise PDCA as a set of exercises and competitive aptitudes during design problem solving. This argument is further explained in sub-section 3.3.4. Yang and El-Haik (2009) also state that the traditional A3 report will make communication more effective when it offers just about the right amount of information for people to understand.

The range of applications of a traditional A3 report is highlighted by Liker and Morgan (2006) and can be presented in four variations: proposal, problem solving, status reporting and competitive analysis. The traditional A3 report represents the solutions by visualised simple sentences, charts and diagrams following the seven elements in a traditional A3 report. All these elements are described in Table 3-4. The seven elements are separately allocated on two sides of A3 paper based on the PDCA learning cycle; the details of the PDCA are explained in sub-section 3.3.4.1. The A3 elements in the traditional A3 report also have inter-relations with other problem solving approaches such as the 5 whys and root cause analysis. The traditional A3 report is one of the mediums to represent the PDCA cycle based on A3 report elements.

Traditional A3 Report Elements	
Plan	**Do, Check , Act**
1. Background Provide the project background information and company goals or historical data as clearly as possible. These two components must be related to each other which at the end of the project will give profit to the company. *Medium solution: Bullet, chart* **2. Current Condition** Represents the actual situation that happened in a simple and easy to understand way. The information is gathered from direct investigation and observation. Outlines the work that has been performed. *Medium solution: Chart, table, graph, timelines, bullet.* **3. Future Goal** Involves several metrics to present a clear goal and measure performance. *Medium solution: Graph, bullet* **4. Root Cause Analysis** Investigates the root cause of the problem from the current situation. Propose possible solution. *Medium solution: Ishikawa, 5 whys, Pareto*	**5. Countermeasures** Measure the issue that happened, the cause of the problem. *Medium solution: Table, 5W 1H, process flow* **6. Implementation Plan** Provide future action plan and verify the effectiveness. *Medium solution: Graph, table* **7. Follow-up Action** Investigate any similar processes in the company that can provide benefit. Address any people in the company that will be affected. *Medium solution: Graph, table*

Table 3-4: Traditional A3 Report Elements (Sobek and Smalley, 2008)

3.3.2 Summary of Problem Solving Approaches Overview

This sub-section summarises the author’s understanding based on the previous sub-section. The effectiveness of the traditional A3 report to solve problems in manufacturing shop-floor cannot be denied; however, the problem solving activities for product design in this research are not only to solve a design problem, but also to capture the created knowledge, hence to provide useful knowledge to designers to be shared and applied for current and future decision making. This useful knowledge, as defined in section 1.1, will be gathered only by providing proper guides and processes to capture and visualise the knowledge in order to support the designers in turning their experiences into proper learning. The latter needs to be clearly defined in order to encourage designers to provide the useful knowledge in an efficient way.

The 5 Whys and root cause analysis (RCA) approaches have been used in product design; however, a lack of empirical research about the traditional A3 report, 8 Disciplines (8D) and problem analysis flowchart (PAF) implementations in product design. Therefore, to support problem solving in product design by using a simple template, it is vital to identify which elements are required. The following section presents inter-relation analysis of the problem solving approaches.

3.3.3 Inter-relation Analysis within Problem Solving Approaches

The significance of these inter-relations analysis for the research points to:

- Facilitating the research to capture and evaluate the approach that is inter-related to other approaches.
- Identifying and finalising the phases to be structured as new elements for a new A3 template as a tool for the proposed A3 thinking approach.
- Understanding their processes and key phases to solve problems. This will lead the research to identify the necessary processes or tools that can probably be applied in the A3 thinking approach.

Table 3-5 presents the five approaches and their key phases. This analysis is based on the key phases structured on their standard templates. The significance of this result is that it will identify some important phases and their tools, e.g. including text, diagram, table, graph, sketch, bullet, and a combination of problem solving phases that could be a good practice for the new A3 thinking approach. Table 3-5 has five main columns representing five problem solving approaches with their key elements ranging from 8D to the PAF. Each of the key elements illustrates the various recommended tools used in their templates and these are explained as a legend at the bottom of the table. The 8D approach has been selected as a standard, shown in italics, as the authors identified that the 8D is the approach with the highest performance, as shown in Table 3-5, and also has the greatest quantity of key phases compared to the traditional A3 report.

	Problem Solving Approaches				
	8 Disciplines (8D) *Standard*	Traditional A3 Report	5 Whys	Root Cause Analysis (RCA)	Problem Analysis Flowchart (PAF)
Key Phases	1. Form the team pitfalls				
		1. Background			
	2. Clarify the problem	2. Current condition		1. Define the problem 2. Collect the data 3. Identify possible causal factors	1. Problem statement
		3. Future goal			
	3. Contain the problem pitfalls				
	4. Identify the root cause	4. Root cause analysis	Why 1 Why 2 Why 3 Why 4 Why 5	4. Identify the root cause (s)	2. Symptoms 3. Changes 4. Relevant data 5. Defect-free configurations 6. Distinction 7. Causal chains
	5. Generate solutions	5. Countermeasures			8. Test, corrections, results and conclusion
	6. Implement permanent solutions	6. Implementation plan		5. Recommend and implement solutions	
	7. Prevent recurrence				9. Most probable cause
	8. Congratulate the team (Validation)	7. Follow-up action			10. Short term and long term corrections and controls

Legend:

Text	Diagram	Graph	Sketch
Bullet	Combination	Table	

Table 3-5: Inter-relation Analysis Phase-to-Phase

The important findings based on the analysis in Table 3-5 are as follows:

- The key phases used in the 5 Whys, RCA and PAF are also used in 8D and the traditional A3 report.
- Key phases 1 (Background) and 3 (Future Goal) in the traditional A3 report do not exist in the 8D approach.
- Key phases 1 (Form the team pitfalls), 3 (Contain the problem pitfalls), and 7 (Prevent Recurrence) in the 8D approach are not included in the traditional A3 report.

The author has also investigated the terminology used by different authors for the various key phases within the various problem solving approaches. However, only two problem solving approaches (traditional A3 Report and 8D) are identified by the author as having used different terms. For the traditional A3 report, eight authors (Shook, 2009; Shook, 2008; Sobek and Smalley, 2008; Ghosh and Sobek, 2006; Sobek, 2006; Ghosh, 2006; Jimmerson et al., 2005; and Sobek and Jimmerson, 2004;) and for the 8D, four authors (Arnott, 2004; Beachell, 2011; Behrens et al., 2007; Kamsu et al., 2008) have been identified as describing the different terminologies. All these terminologies have been added and are represented in Table 3-6 which in turn results in 25 different key phases. The reason for investigating the different terms used by those authors is to finalise the key phases (elements) and produce a summarised definition to be used and described in a new A3 template. From the analysis, the author has identified the ten elements that could be applied to solve a problem in product design by using a new A3 template that will support the knowledge-driven design based on the new A3 thinking approach presented in Chapter 5. The ten final elements that have been selected to be structured into a new A3 template as presented in Table 3-6 are; (1) Team, (2) Background, (3) Current condition, (4) Future goals, (5) Containment, (6) Root cause analysis, (7) Proposed solutions, (8) Implementation plan, (9) Prevent recurrence, and (10) Follow-up action. Therefore, the new A3 template engaged all the phases from problem solving approaches. In order to make these elements easier to remember, the terms have been shortened. The elements have been selected based on the findings from the reviewed literature in sub-section 3.3.1 and Table 3-5 where the selected elements have been used and have a strong potential to be used in product design.

No.	Key Phases of Problem Solving	8D	Traditional A3	New A3 Template	Elements to be used
1	Form the team pitfalls	✓		✓	Team
2	Theme/Background		✓	✓	Background
3	Current condition/Problem Statement		✓	✓	Current Condition
4	Clarify the problems	✓			
5	Future goals/Target condition		✓	✓	Future Goals
6	Symptoms				
7	Changes				
8	Relevant Data				
9	Defect free configurations				
10	Distinction				
11	Contain the problem pitfalls	✓		✓	Containment
12	Causal chain				
13	Test, correction, results, and conclusion				
14	Most probable cause				
15	Root cause analysis	✓	✓	✓	Root Cause Analysis
16	Short term and long term corrections and controls				
17	Countermeasures		✓		
18	Generate solutions	✓		✓	Proposed Solutions
19	Implementation plan		✓	✓	Implementation Plan
20	Recommendation		✓		
21	Check & Confirmation of effect		✓		
22	Implement permanent solutions	✓			
23	Prevent recurrence	✓		✓	Prevent Recurrence
24	Follow-up action		✓	✓	Follow-up Action
25	Congratulate the team	✓			

Table 3-6: Different Elements Used among Problem Solving Approaches

This research focuses on development of a new problem solving approach and process for product design based on learning organisation to support lean product and process development. Thus, several learning cycles are identified and explained in the following sub-section. The intention is to investigate how the knowledge created should be involved as part of the continuous learning cycle, and how efficient the current learning cycles are in encouraging the problem solvers to interpret and represent the created knowledge after having solved a design problem.

3.3.4 Learning Cycles for Product Design

The learning cycle is the continuous and overlapping process which leads to improved performance, process improvement and problem solving. One of the important aspects of the learning cycle in this research is the creation of knowledge. This knowledge is created, captured and shared in different forms, such as lessons learned, idea generation and decision making. In addition, the effectiveness and efficiency of product development highlights from knowledge-based development is entirely affirmed on the ability to create and reuse knowledge (Oosterwal, 2010). The aim of the new A3 thinking approach proposed and explained in Section 1.4 is to aid the generation of knowledge-driven design to support decision making within the LeanPPD environment. Yang and El-Haik (2007) states that lean product design needs to be free from unnecessary complexities. The sustainability of lean transformation in product design requires continuous improvement in problem solving which is guided by the learning cycle. This statement matches two of the management principles provided by Liker and Morgan (2006) as a foundation for lean product development, which are:

- Principle 1 – build in learning and continuous improvement
- Principle 2 – use powerful tools for standardisation and organisational learning

Therefore, for this thesis, the knowledge-driven design stemming from efficient problem solving approach and the appropriate learning cycle will provide a knowledge-rich environment. The author has identified several learning cycles that have already been applied in product development or manufacturing on the shop-floor (Erixon and Kenger, 2004; Ward, 2007), namely as Plan-Do-Check-Act (PDCA), Look-Ask-Model-Discuss-Act (LAMDA), Define-Measure-Analyse-Improve-Control (DMAIC- Six Sigma) and Identify-Design-Optimise-Verify (IDOV - Design for Six Sigma). However, based on their terminologies, LAMDA as a knowledge creation cycle is a more straightforward approach and easier to understand than the PDCA. Despite the short title of PDCA, people sometimes misunderstand the implications and requirements of ‘Do’ and ‘Act’ in the acronym (Domb and Radeka, 2010). Regarding the DMAIC (Six Sigma) and IDOV (Design for Six Sigma) learning cycles, Yeh et al. (2010) find that they are given low priority and are not comprehensivelly used in product development. In addition, DMAIC and IDOV are statistical approaches frequently performed as computational tasks. Therefore, the research selected two learning cycles that are familiar in problem solving and as a reference for product design. Those learning cycles are the Plan-Do-Check-Act (PDCA) and Look-Ask-Model-Discuss-Act (LAMDA). These two learning cycles will be discussed in further sub-sections.

3.3.4.1 Plan-Do-Check-Act

The traditional A3 report is an approach to perform Plan-Do-Check-Act (PDCA) to solve problems at the manufacturing shop-floor. PDCA is a continuous improvement cycle and a basic philosophy of the traditional A3 thinking (Sobek and Smalley, 2008). It is a management cycle and framework that derives from the Shewhart cycle (named after the first person to discuss the concept of the PDCA cycle). The PDCA not only leads to problem solving but also is a good learning cycle. The reason for this is that PDCA helps engineers to slow down enough to understand the problem, collect the information, and develop ideas before proceeding to full implementation. The brief of the PDCA is explained as follows: The ‘plan’ stage is critically important to start by gaining agreement on where an organisation really stands, i.e. on its “current state.” This means developing simple, visual measures of current performance that everyone can see and agree on. The ‘do’ stage will succeed if the plan tells a simple, persuasive story and each element of the plan is easily understandable by everyone. Toyota’s A3 report describes on a single sheet of paper the issue each plan element is addressing. Here, the simple and small experiments and ideas are developed in order to minimise disruptions in the process routine. The ‘check’ stage of the plan is critical and is almost universally ignored. At this stage, the small experiment or scale from the second stage will continuously check and measure. All the results or any changes will be documented and analysed because from here, problem solvers will identify the possible issues that will occur after implementing the solution. However, as yet there is no point in starting to deploy a plan unless there is a standardised method for measuring the results and leadership commitment to follow through.

The 'act' or 'adjust' step is equally important but requires effective problem solving to understand why the plan is not achieving its intended results. Even organisations that check their progress are usually very weak at adjusting. Yet almost no plan, even at Toyota, produces exactly the results expected (Womack and Jones, 2003).

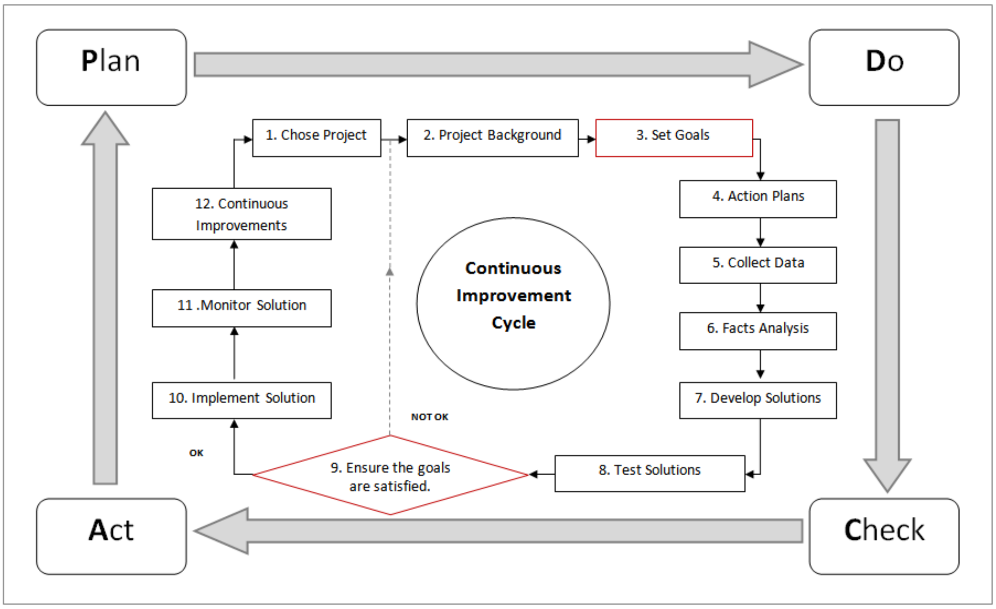


Figure 3-8: PDCA Continuous Improvement Cycle

Figure 3-8 represents the PDCA continuous improvement cycle which consists of twelve steps gathered from a multiple analysis of PDCA articles. The author has separated the twelve steps involved for each phase of the PDCA cycle. Most importantly, the ninth step shows the critical PDCA implementation where the engineers and designers are required to measure the goals' achievements. If the goals are not satisfied, then they have to restart from the third step by considering developing alternative solutions. According to the explanation, PDCA proves that the key to solving problems is to capture and create knowledge based on the third and last step in PDCA. Even though PDCA is only a short name, frequently people confuse what the requirements and relations between 'Do' and 'Act' are (Radeka, 2006).

3.3.4.2 Look-Ask-Model-Discuss-Act

In 2002, when Allen Ward was teaching PDCA to his product development clients, he realised there was a gap of implementation of PDCA due to dissimilarities of the results between Toyota and Allen's American clients. Hence, Allen stated that PDCA was not the best framework for all companies because of the urgent or critical problems that had to be solved, so he developed LAMDA to close the gap (Radeka, 2012). LAMDA is the acronym of Look-Ask-Model-Discuss-Act and is a cycle of knowledge creation (Ward, 2007). This learning cycle is for lean product development to solve and correct the problems in a short time, economically and to prevent people from confusing what occurs within 'Do' and 'Act' in the PDCA learning cycle. This model creates the necessary actions for developing solutions through usable knowledge (Kennedy et al., 2008). Oosterwal (2010) states that a LAMDA cycle is based on necessary actions to identify, refine and address the problems through application of knowledge. LAMDA prevents waste (especially rework or redesign waste) and unnecessary meetings; also, it is easy to understand, apply and remember. It focuses on sharing knowledge and producing common agreements. The brief LAMDA cycle process is described as follows:

- Look – This step will involve activities such as communication, observation and investigation to determine the best and most useful information, and possible knowledge. In this step both kinds of knowledge are required: tacit knowledge collected from first-hand experience and explicit knowledge gathered from reports and other documents (Radeka, 2012). Most important is to go to, look at and observe the problem area.
- Ask – Here, the application of the 5 Whys approach will give the greatest influence on how to solve the problem. Who, why, where, what, when and how will also be asked many times until the maximum information and data are reached.
- Model – At this stage, the problem solver will model simple ideas to help articulate thinking in order to visualise the knowledge based on the information

derived from the look and ask steps. The best visualisation is from those of sketches, graphs, charts, diagrams or drawings.

- Discuss – This step is very important where the discussion is among the engineers involved in brainstorming the model to refine the ideas for implementation (Radeka, 2012). There are three people considered to be important in the discussion step: the person who will be impacted on by the solution, the person who is involved in the Ask step and the person who will make the final decision.
- Act – After the final decision has been made, the model is ready to act on and implement.

The development of the LAMDA learning cycle, shown in Figure 3-9, is to help the designers to reach an actual solution, similar to PDCA.

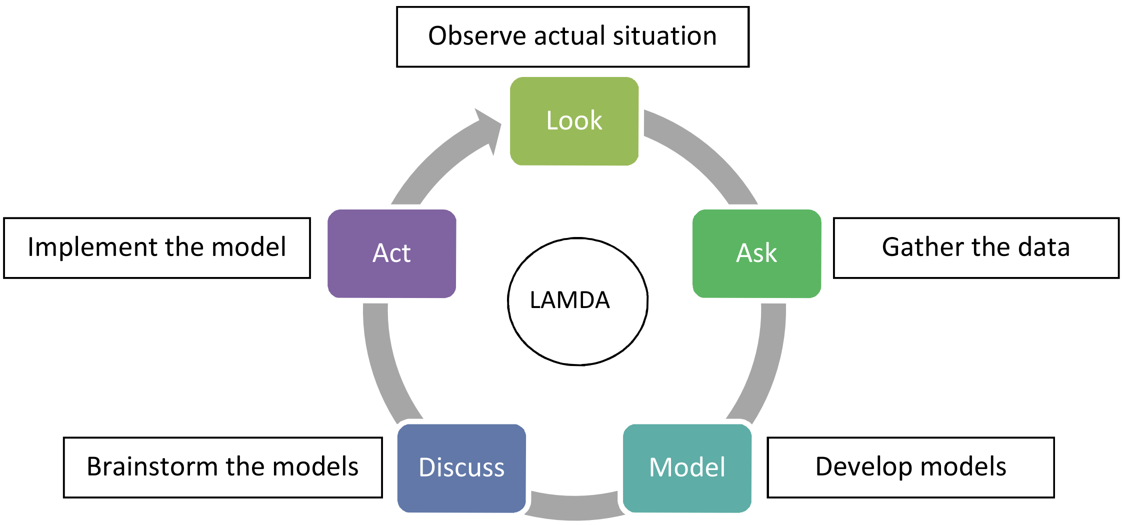


Figure 3-9: LAMDA Knowledge Creation Cycle (Radeka, 2012)

The inter-relations of PDCA and LAMDA are explained by Radeka (2006) when she highlighted that one cycle of PDCA is equal to two LAMDA cycles. Khan et al. (2010) highlight that PDCA and LAMDA are the generic approaches of learning cycles which help designers and engineers to be empowered in order to make decisions and sustain an expert workforce. The next section presents the suitable learning cycle from the aforementioned learning cycles (PDCA and LAMDA) to be selected for the new A3 thinking approach.

3.3.5 The Appropriate Learning Cycle for the New A3 Thinking Approach

LAMDA as a cycle of knowledge creation, as developed by Ward (2007), combines five of Toyota's requirements, such as 'genchi genbutsu' (go see for yourself), 5 Whys (Ask 'why' 5 times), 'nemawashi' (consensus building), 'hansei' (Reflection events), and 'kaizen' (continuous learning). Most importantly, genchi genbutsu, nemawashi and kaizen are a part of the 14 'Toyota way' principles (Liker, 2004; Ward, 2007). Sun and Zhao (2010) state that kaizen can shorten the development process, minimise product cycle time and improve product quality. Martinsons and Davison (2007) find that the requirement of consensus building (nemawashi) by face-to-face meetings is preferred by the Japanese managers for oral more than textual cues. This requirement enables them to listen to co-workers from the shop-floor upwards prior to making a decision.

Mefford (2009) finds that much of the knowledge distributed throughout the organisation is gained by actually undertaking the process analysis activities according to a structured approach guided by the scientific method 'genchi genbutsu'. This Japanese term, meaning 'go and see' is particularly right for the Toyota way for this process of learning where the workers will learn to be successful process improvers by conducting the process over and over again. The five Toyota's requirements are placed together for the LAMDA learning cycle and therefore LAMDA is an appropriate tool for A3 problem solving not only because the implementation is clearly explained and understandable for each of the acronyms, but also because it is defined as an important exercise in the Toyota way.

The author has also defined the similarity of the PDCA and LAMDA learning cycles. The 'Plan' step in PDCA is equal to the 'Look - Ask' steps in LAMDA where all these steps are performed as an exercise to gain the necessary and proper information to address the problem before proceeding to the next steps of 'Do' in PDCA and 'Model' in LAMDA. The skill of addressing the root cause of the problem is important to ensure a desired solution. This thesis has identified the gaps in the implementation of the PDCA learning cycle where: a) the PDCA learning cycle in the traditional A3 report is not presentable as a way to encourage designers to perform continuous improvement in problem solving for product design, and b) the first action in the PDCA learning cycle, 'Plan' is presented as a 'noun' to a designer to address a problem. Instead of the first and second actions in the LAMDA learning cycle, 'Look – Ask' are developed to build a designer's mind as in the Japanese thinking of 'do it yourself'. In a nutshell, LAMDA is a contributor to PDCA. The following section identifies knowledge management capability for the A3 thinking approach to aid the generation of knowledge driven design to support decision making in product design.

3.4 Knowledge Management Capability to Support Knowledge Driven Design

3.4.1 The Role of Knowledge Management in Product Design

Knowledge, as a justified true belief (Nonaka, 1994), stems from the heart of organisational capabilities and the process of managing knowledge in order to meet customers' requirements when designing a product, making the role of knowledge management crucial (Shahalizadeh et al., 2009). Jennex (2005) defines knowledge management as "the process of selectively applying knowledge from previous experiences to current and future decision making activities with the explicit purpose of improving effectiveness". Knowledge management is a set of actions that needs to be developed in order to ensure that the knowledge reaches the right person at the right time. Knowledge consists of two main types, namely explicit and tacit, which are essential to knowledge creation (Alwis and Hartmann, 2008). Explicit knowledge is what can be verbalised and interpreted easily, whereas tacit knowledge is hard to formalise and document (Nonaka, 1994). However, both types of knowledge are essential to support decision making. Therefore, this research is developing a novel approach by creating and capturing both explicit and tacit knowledge in a simple template. This could enhance the effectiveness of knowledge sharing and reuse, as it is a requirement for next-generation product development (Dani et al., 2006).

Goffin et al. (2010) define that new product development, as a learning process, relies on generating and sharing knowledge while Mital et al. (2008) state that new product development can be considered as a series of problem solving activities where the design solutions play a key role in the contribution to knowledge (Lawson, 2006). The role of knowledge in designing a product becomes the primary source of sustainable competitive advantage, identified by short product life-cycles and complex processes (Ramesh and Tiwana, 1999). The knowledge used in designing a product is dynamic and, in order to apply it effectively, it must be allowed to evolve during the design process (Candy and Edmonds, 1996). Therefore, the design team needs an informative and simple approach to creating, tailoring and sharing new knowledge.

Parry and Turner (2006) state that information overload has become a common problem in product development today where engineers tend to be confronted with huge amounts of documentation. Mohd Saad et al. (2012(a)) find that current challenges have been faced with regards to knowledge capture and representations that are known to be too time consuming, and difficult to extract already captured knowledge. Additionally, in practice, most of the engineers do not document the justifications and rationale from past design decisions which is a part of knowledge management. This has increased the complexity in accessing existing design knowledge which is due to this lack of formal representation; hence it is difficult for even experienced design engineers to trace past design knowledge (Tang et al., 2010).

This section clearly explained that knowledge management becomes a more complex and important activity, which means that the incorporation of the previous knowledge created is essential. Put simply, the idea of the A3 thinking approach as explained in the first chapter is to develop concise problem solving that yields a concise solution that could make it easier for the designers to capture and visualise the created knowledge. A concise knowledge visualisation will encourage designers to capture and obtain useful knowledge surrounded by a knowledge-rich environment.

3.4.2 Determination of Knowledge Management Capability

For this research, the capability is a contributor to effective knowledge management for organisational performance therefore, it is important to identify. The intention is to analyse the different problem solving approaches (explained in sub-section 3.3.1) in an efficient way by considering the knowledge management capability of each approach in order to identify their performance in solving problems and to create knowledge. Developing a new A3 thinking approach which stems from the appropriate knowledge management capability will lead to greater competitiveness. Therefore, the type of capability in knowledge management based on problem solving activities in product design has been defined, namely: knowledge creation, capture and sharing. This identification is based on the following issues and challenges in organisational knowledge management;

- Zhai et al. (2012) state the central theme in field of knowledge management in companies is the challenges of tacit knowledge capture and sharing.
- Ouertani et al. (2011) find that product knowledge sharing is becoming a key issue for the information system during the design and manufacturing phases.
- Borches and Bonnema (2010) conclude from their survey that the main improvement barriers are: communication within disciplines and divisions, dealing with complexity, discovering the required system information and knowledge sharing. They identify that those barriers, especially the lack of knowledge sharing were the root causes of many enlargement problems and bad decisions in design.
- Tang et al. (2010) conclude that it is very important to ensure the efficiency of knowledge capture, sharing and reuse in a structured manner to support new product development.
- Huang and Liang (2006) state “Product design is such a business process that a great part of the design knowledge is often a tacit type, being difficult to capture and share, or available only in forms of natural language documents”.

- Hari et al. (2005) define knowledge capture as being a challenge for the organisation but the issues of knowledge creation, capturing and sharing knowledge have the most important role in managing organisational knowledge.
- King et al. (2002) also state that knowledge creation and distribution issues have been dealt with for decades in organisational knowledge management.

The above indicates that the major current issues in managing product development knowledge are identified as knowledge creation, knowledge capture and knowledge sharing. These three capabilities seem to play a vital role in managing product development knowledge as a key to the innovation in product design. However, the success of innovation is achieved when the problem solving competence has been considered (Atuahene-Gima and Wei, 2011). Therefore, for this thesis, knowledge management capability for product design refers to the designer's capability to create, capture and share both explicit and tacit knowledge in a simple manner for design problem solving.

The development of the proposed A3 thinking approach by considering these capabilities will eliminate any increase in the number of challenges in product development knowledge management mainly for product design. The author has selected an appropriate definition to ponder for each capability. This helps the author to develop a novel A3 thinking approach to support knowledge driven design for problem solving that combines all these capabilities;

1. Capability 1: Knowledge Creation

   Jurie (2008) states that knowledge creation is the basis for innovation and competitive advantage that can be created through defining the problems, developing and applying solutions in order to solve those problems and further expand new knowledge through the action of problem solving.

2. Capability 2: Knowledge Capture

Hari et al. (2005) state effective knowledge capture is about turning personal knowledge into group knowledge, in accordance with the organisation's strategy, which can then be widely shared.

3. Capability 3: Knowledge Sharing

Knowledge sharing is defined as the distribution of knowledge through the whole department, which plays an important role in knowledge management (Yang, 2004).

3.4.3 Analyses of Problem Solving Approaches Based on the Knowledge Management Capabilities

The problem solving approaches, as explained in sub-section 3.3.1, are analysed according to their performance in solving design problems by considering the aforementioned knowledge management capabilities. This is important as all these capabilities are defined with the aim of developing a simple problem solving approach, which links to the statement from Kim et al. (2009). They describe how a well-structured presentation and narrative-style documentation after a problem has been solved is vital. This is because some of the narrative-style reports fail to allow the problem solvers to understand the cause but also address the interactions between the causes and effects of the problem. The reason for this is that these interactions are very complex and not well-defined and structured, particularly in more complicated cases.

The author has defined the capability of knowledge creation for this thesis as: activities starting from visualising the essential process and information to then address the problem in product design. Lindlöf et al. (2012) define that visualisation has been proved to be a powerful method as the brain can process images more easily than texts in knowledge management. Knowledge is created through the activities of generating and implementing the solutions and measuring the results. During this activity, the Look-Ask-Model-Discuss-Act (LAMDA) as a knowledge creation cycle, as explained in sub-section 3.3.4.2, will guide designers to solve the problem and empower them to make decisions. For the capability of knowledge capture, the author has defined this as an activity in reflecting on the lessons learned and understanding during and after solving a design problem. Meanwhile, the capability of knowledge sharing is an activity for creating and presenting useful knowledge gathered from the problem solving process in a simple manner. Here, 'useful knowledge' is defined as knowledge derived from a systematic process that enables designers to understand the linkage between hypotheses and practice which results in a new learning and understanding. Hence, formulating it into a design rule or design recommendation to be shared and communicated to solve and prevent recurrence of design problems in the future. All these activities are to support the two key principles of the LeanPPD model; knowledge based environment and continuous improvement as explained in Section 1.6.

The knowledge management capabilities of creation, capture and sharing were defined from the identification and investigation of issues and challenges in organisational knowledge management, as explained in sub-section 3.4.2. The following highlighted the five features which have been derived from knowledge management capabilities of creation (a-c), capture (d) and sharing (e). The features are an aspect that needs to be considered in order to perform 'knowledge management capability level analysis' to analyse the impact and performance of the five problem solving approaches. Therefore, five features are defined, namely:

a) Visualise the necessary process and information to address the problem,
b) Present the generation and implementation of the solutions,
c) Provide the process of the learning cycle for knowledge creation,
d) Present reflections on the lessons learned, and
e) Create useful knowledge concisely from those actions, to be shared and communicated.

The idea is to identify the limitations of the five problem solving approaches selected in sub-section 3.3.1 as any limitations will in turn affect the organisational knowledge management. In addition, identification of the limitations will help in the development of best practices for the new A3 thinking approach for product design based on such identification.

3.4.3.1 Limitations of the Traditional A3 Report

The review in sub-section 3.3.1.5 shows that the effectiveness of the traditional A3 report in solving a problem cannot be denied; however, the problem solving activities for product design in the thesis are not only to solve a design problem but also to provide efficient useful knowledge to designers for future decision making. In order to identify the capability of the A3 report in knowledge creation, capturing and sharing, the reviewed literature has been analysed against the defined features and it was found that the A3 report:-

a) Visualises the necessary process and information to address the problem,
b) Presents the generation and implementation of the solutions,
c) Does not provide the appropriate process of the learning cycle for knowledge creation (but the PDCA learning cycle has been used for the A3 report as a continuous improvement cycle (Sobek and Smalley, 2008)),
d) Does not present reflection on the lessons learned, and
e) Does not create useful knowledge concisely from those actions to be shared and communicated.

The above analysis indicates that the traditional A3 report only has the first and second features, with some being performed at the third feature.

3.4.3.2 Limitations of 8 Disciplines

In sub-section 3.3.1.4, it has been identified that the 8 Disciplines (8D) approach has been used and described in both product design and the supply chain in the organisation with specific disciplines, i.e. the fourth and fifth (See Table 3.3). In order to identify the capability of the 8D in knowledge creation, capturing and sharing, the reviewed literature has been analysed against the defined features and it was found that the 8D:

a) Visualises the necessary process and information to address the problem,
b) Presents the generation and implementation of the solutions,
c) Does not provide the process of the learning cycle for knowledge creation,
d) Does not present reflections on the lessons learned, and
e) Does not create useful knowledge concisely from those actions to be shared and communicated.

The above analysis shows that the 8D only has the first and second features.

3.4.3.3 Limitations of Root Cause Analysis

In order to identify the capability of the Root Cause Analysis (RCA) in knowledge creation, capturing and sharing, the reviewed literature in sub-section 3.3.1.2 has been analysed against the defined features and it was found that the RCA:

a) Visualises some of the necessary processes and information to address the problem (Identify the root cause of the problem),
b) Does not present the generation and implementation of the solutions,
c) Does not provide the process of the learning cycle for knowledge creation,
d) Does not present reflections on the lessons learned, and
e) Does not create useful knowledge concisely from those actions to be shared and communicated.

The above analysis indicates that RCA is only performed to some extent in the first feature.

3.4.3.4 Limitations of the 5 Whys

In order to identify the capability of the 5 Whys in knowledge creation, capturing and sharing, the reviewed literature in sub-section 3.3.1.1 has been analysed against the defined features and it was found that the 5 Whys approach:

a) Visualises some of the necessary processes and information to address the problem (Identify the root cause of the problem),
b) Does not present the generation and implementation of the solutions,

c) Does not provide the process of the learning cycle for knowledge creation,
d) Does not present reflections on the lessons learned, and
e) Does not create useful knowledge concisely from those actions to be shared and communicated.

The above analysis indicates that the 5 Whys only performed to some extent in the first feature, similarly to the RCA approach.

3.4.3.5 Limitations of Problem Analysis Flowchart

The literature search in sub-section 3.3.1.3 found no reference to or evidence of using the same template to solve a design problem. However, this approach has been applied in some manufacturing processes, such as productivity in production, tripping overload and high-pressure faults. All these problems require continuous observation in the manufacturing process, since it is necessary to perform the test and validate the corrections several times (Sproull, 2001). The advantage is that an inexperienced person will be able to understand clearly how to solve a similar problem by looking at the provided template. In order to identify the capability of the Problem Analysis Flowchart (PAF) in knowledge creation, capturing and sharing, the reviewed literature has been analysed against the defined features and it was found that the PAF:

a) Visualises the necessary process and information to address the problem,
b) Presents the generation and implementation of the solutions (but not the implementation of the solutions),
c) Does not provide the process of the learning cycle for knowledge creation,
d) Does not present reflections on the lessons learned, and
e) Does not create useful knowledge concisely from those actions to be shared and communicated.

The above analysis shows the PAF only has the first feature and some performed at the second feature.

3.5 Limitations Summary of Problem Solving Approaches

The five problem solving approaches have been reviewed in the previous sub-sections and are presented in Table 3-7. This table presents the summary of the knowledge management capability level analysis based on knowledge creation, capturing and sharing against the defined five features presented in sub-section 3.4.3.

Features	Problem Solving Approaches				
	A3	8D	RCA	5 Whys	PAF
a) Visualise the necessary process and information to address the problem	✓	✓	-	-	✓
b) Present the generation and implementation of the solutions	✓	✓			-
c) Provide the process of the learning cycle for knowledge creation	-				
d) Present a reflection on the lessons learned					
e) Create useful knowledge concisely from those actions to be shared and communicated.					
- Only some are performed.					

Table 3-7: Analysis Summary Based on the Capabilities of the Problem Solving Approaches

Table 3-7 clearly shows there is no approach that incorporates all the features. This means there is a gap in supporting a knowledge-driven design of problem solving to support decision making and reduce design mistakes. Therefore, the new A3 thinking approach aims to aid the generation of knowledge driven design by addressing all the five features to support decision making within LeanPPD environment. All the features will guide designers to reach the right solution by providing a process to solve problems and capture the useful knowledge gathered from the implementation of the features. In addition, a new A3 template will support the communication and share the created knowledge. This will enable designers to solve a problem whilst enriching the environment of knowledge creation efficiently. The knowledge created efficiently from those features is most important in ensuring that the proposed approach will represent the provision of useful knowledge to support knowledge driven design within a knowledge based environment. This is how the new A3 thinking approach will support the LeanPPD as explained in Section 1.6.

3.6 Research Gaps

A review of previous literature has identified that more research is needed into the contribution of the problem solving approaches for knowledge management in product design. This has provided the foundation for a new problem solving approach. The following highlights the research gaps that were identified and summarised based on the reviewed literature:

1. There is a lack of discussion and little empirical data for the utilisation of the aforementioned problem solving approaches in product design.
2. The current problem solving approaches do not satisfy the knowledge management capabilities to support knowledge driven design. The limitations within the problem solving approaches have been explained in Section 3.5 and summarised in Table 3-7.
3. There is no comprehensive problem solving approach that formally integrates the capability of knowledge creation, capture and sharing in a simple manner as analysed and explained in sub-section 3.4.3.
4. There is a gap in defining a problem solving approach to support the LeanPPD environment.

3.7 Chapter Summary

This chapter reviews and analyses the problem solving approaches for lean product development. In Section 3.1 the author introduces the focal points of this chapter. Section 3.2 focuses on the understanding of new product development specific to the research area of the initial phase in product development. A review of lean product development continues by focusing on the fundamentals of lean thinking in order to understand the application of lean in product development. This has led the research to the identification of evolving issues in lean product development. Section 3.3 reviews the problem solving approaches in product design. Five problem solving approaches (5 Whys, Root Cause Analysis, Problem Analysis Flowchart, 8 Disciplines and A3 report) are evaluated and their impacts and applications investigated. The appropriate learning cycle (LAMDA) and the applications and impacts are identified and evaluated. Section 3.4 is associated with knowledge management capabilities, which is the last major topic of the reviewed literature. The author presents the role of knowledge in product design, and the capabilities of knowledge for the A3 thinking approach are determined (knowledge creation, capture and sharing) and analysed within the problem solving approaches. The limitations of the approaches to generate knowledge driven design have been identified as presented in Section 3.5. The development of the new A3 thinking approach will address the limitations in order to achieve the research aim. Section 3.6 highlights the research gaps that were identified during the literature review and analyses. The following chapter explains the industrial perspective of problem solving and knowledge management capability gathered from data collection methods.

Chapter 4

4 INDUSTRIAL PERSPECTIVES OF PROBLEM SOLVING APPROACHES AND KNOWLEDGE CAPTURE

4.1 Introduction

This chapter presents the industrial perspectives of problem solving approaches and knowledge capture from the automotive sector. Section 4.2 explains the semi-structured interviews and detailed data collection and analyses gathered from document review, direct observation and focus group are explained in Section 4.3. Finally, this chapter is summarised in Section 4.4.

4.2 Industrial Field Study

The semi-structured interviews are using the close-ended questionnaire as presented in Appendix 5. The interviews were conducted in the automotive sector within two companies. For confidentiality reasons, the different companies' names have been removed. Table 4-1 shows a list of key roles and years of experience of the respondents for the semi-structured interviews in the companies. The data collection ran for a minimum of two days for each company in collaboration with other researchers involved in the LeanPPD Cranfield University team. A total of 25 respondents were involved in the data collection and were interviewed one-by-one, taking approximately one hour per respondent. For each interview, the author asked specific questions relating to the issues and challenges in design problem solving to augment the understanding. Some of these questions were as follows:

- Do you have a standard template for all the approaches and if so do you formally implement it?
- To which process in product development did you apply the problem solving approaches?
- What are the impacts of using the current problem solving approaches?
- What are the challenges of knowledge capture and sharing?

Respondents	Key Roles	Years of Experience
1	Senior Manager Direct Purchasing	22
2	Process Development Manufacturing Engineering	35
3	Forward Planning, Commitment Control	22
4	Manager Plan	28
5	Vice President Manuf. Company Y Group Transmissions	33
6	Vice president purchasing	22
7	PD Core Engineering, Mechatronic Systems	24
8	Director Product Segment Dual Clutch Transmissions	21
9	Verification, Testing & Attribute Eng. Manager	16
10	Platform Director Power shift DCI/DLL, Vice President	15
11	Vice President Product Development Platform Director	10
12	Senior Manager Direct Purchasing	10
13	Vice president purchasing	15
14	Electrical Engineer	2
15	Senior Electrical Engineer	4.5
16	TIS Lead Engineer	5
17	EMC Application Engineer	7
18	Electronics Design Engineer	4.5
19	Electronics Engineer	9
20	Radio Electrical Engineer	9
21	Technical Fellow	19
22	Electronics Design Engineer	10
23	Electrical Design Engineer	10
24	Technical Fellow Electronics Engineer	8
25	Electrical Engineer	6

Table 4-1: Details of Respondents for Semi-structured Interviews

Seven close-ended and hypothetical questions were included in the questionnaire. Four topics were selected and structured in the questionnaire after considering the key principles of LeanPPD model as presented at Figure 1-2 in Chapter 1: a) learning cycle for continuous improvement, b) problem solving in product design, c) knowledge management capability, and d) hypothetical question. Each of these topics is provided with one or more design questions. The results have been analysed using Microsoft Excel 2007. The following presents the interview analysis based on the four topics as below.

a) Learning cycle for continuous improvement

Rationale: The questions for this topic were designed to examine the type and application of learning cycles as a guide to solving problem in the collaborative companies. Based on the literature review, the learning cycle becomes a catalyst to improve performance, process improvement and problem solving where it leads to the creation of useful knowledge. Therefore, it is critical to identify the use of the learning cycle in product design within the collaborative companies. There are two questions raised here and the results explained as follows:

Question 1: Do you use learning cycles as guidelines for continuous improvement?
Result: Figure 4-1 shows that, 38% and 46% of the industries are applied loosely and never using a learning cycle. This has been identified as being where they lack understanding on how to formally implement the learning cycle. This shows that more work is required to enable the formal use of a learning cycle for continuous improvement.

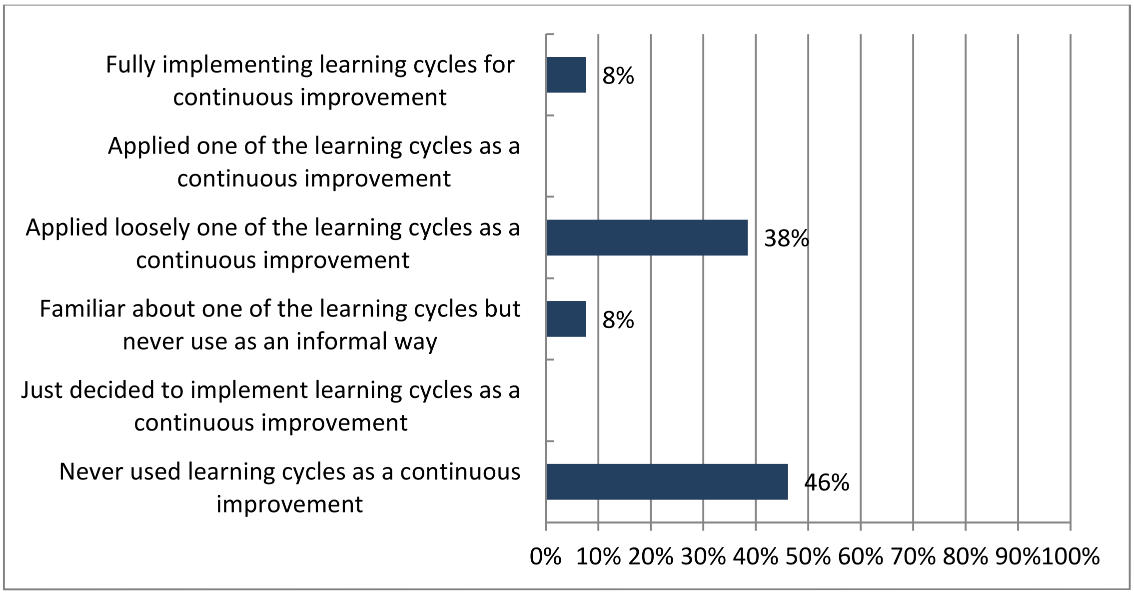


Figure 4-1: The Use of Learning Cycles

Question 2: Which of the following learning cycles have you formally implemented as a guide to continuous improvement in your company? How effective do you find them?

Result: As shown Figure 4-2, the PDCA learning cycle has less frequency, but all the respondents realise the effectiveness of PDCA. This could be due to the utilization of the PDCA provided by the company does not encourage them to use PDCA. Therefore, adopting a simply approached learning cycle could help the designer to perform well. For the LAMDA learning cycle shown 0% for both effectiveness and frequency, which suggest that, the respondents had never heard of or used it. However, some respondents claimed that they were using a LAMDA learning cycle based on the LAMDA interpretation (Look-Ask-Model-Discuss-Act) but they did not apply it formally.

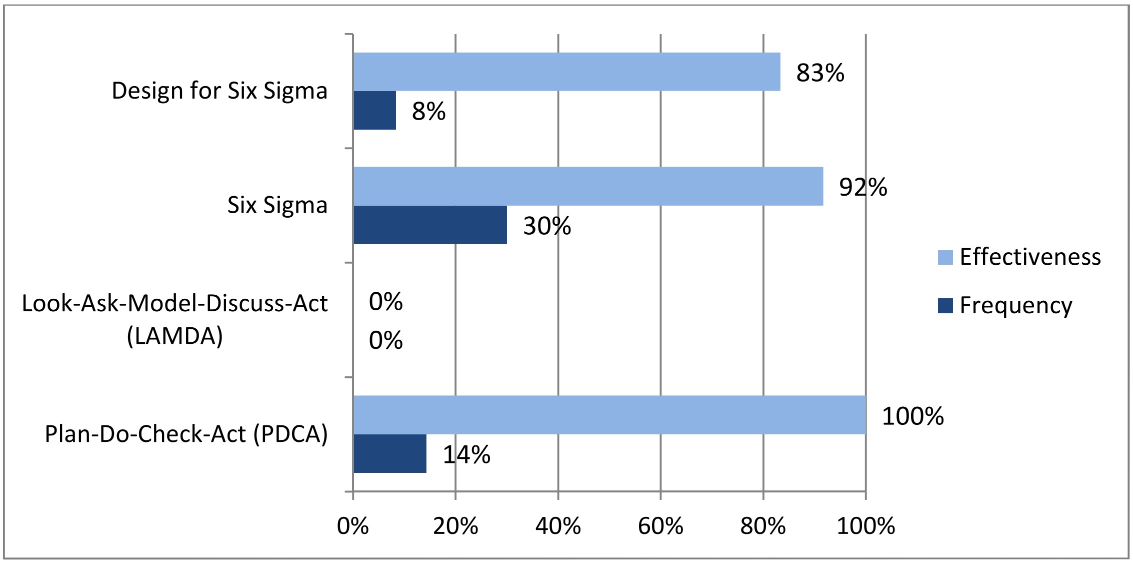


Figure 4-2: The Effectiveness and Frequency of Types of Learning Cycles

b) Problem Solving in Product Design

Rationale: The questions for this topic were structured in order to discover the current practices of problem solving approaches and process in product design and development. The listed approaches and process are gathered from literature reviews where all of them are represented and implemented as a document template, and in addition, to capture the elements considered as important information during problem solving. The results helped the author to finalise and structure a new A3 template that would be developed from the important elements the companies needed. Therefore three questions were designed and the results presented as follows:

Question 1: Which of the following approaches have you formally implemented as a tool to solve problems in product design and development?

Result: Figure 4-3 shows most of the problem solving approaches having more than 50% of effectiveness, including the traditional A3 report. Although the traditional A3 report is less effective compared to the others, this is due to its less frequency of use by the respondents.

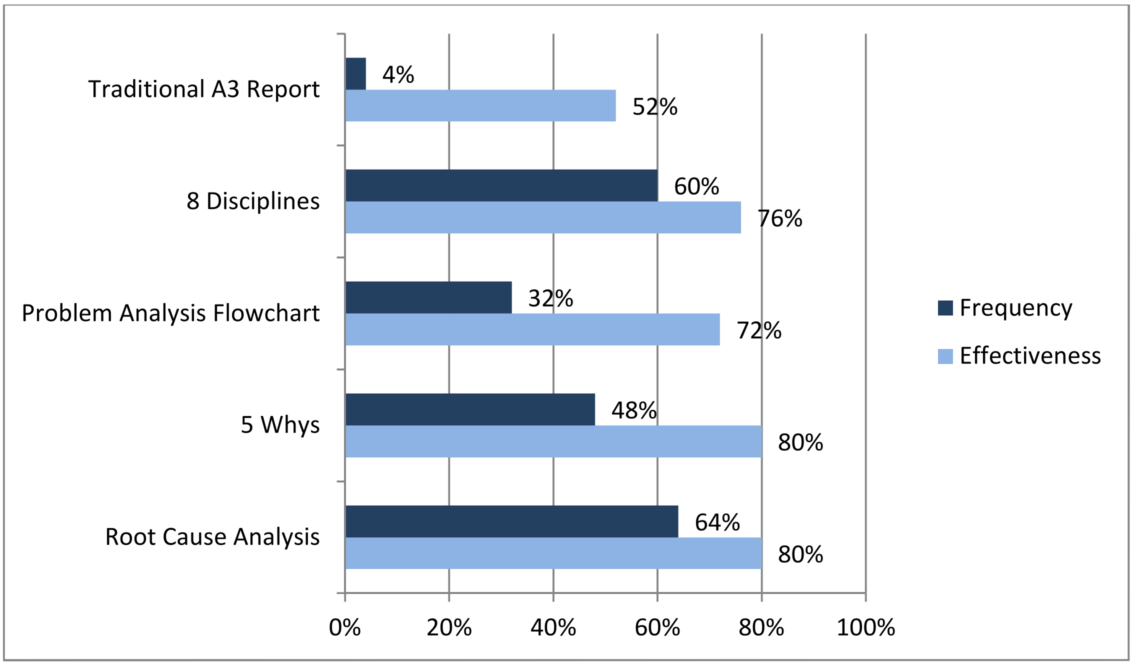


Figure 4-3: The Effectiveness and Frequency of Problem Solving Approaches

Question 2: Which of the following elements must be considered as important elements during problem solving in product and process design?

Result: Figure 4-4 indicates that all the elements have more than 80% importance except for future goal, containment and follow-up action. The future goal and follow-up actions are the elements structured in the traditional A3 report whilst containment is in the 8D approach. This result helps the author to identify important elements and also to eliminate unnecessary elements for a new A3 template.

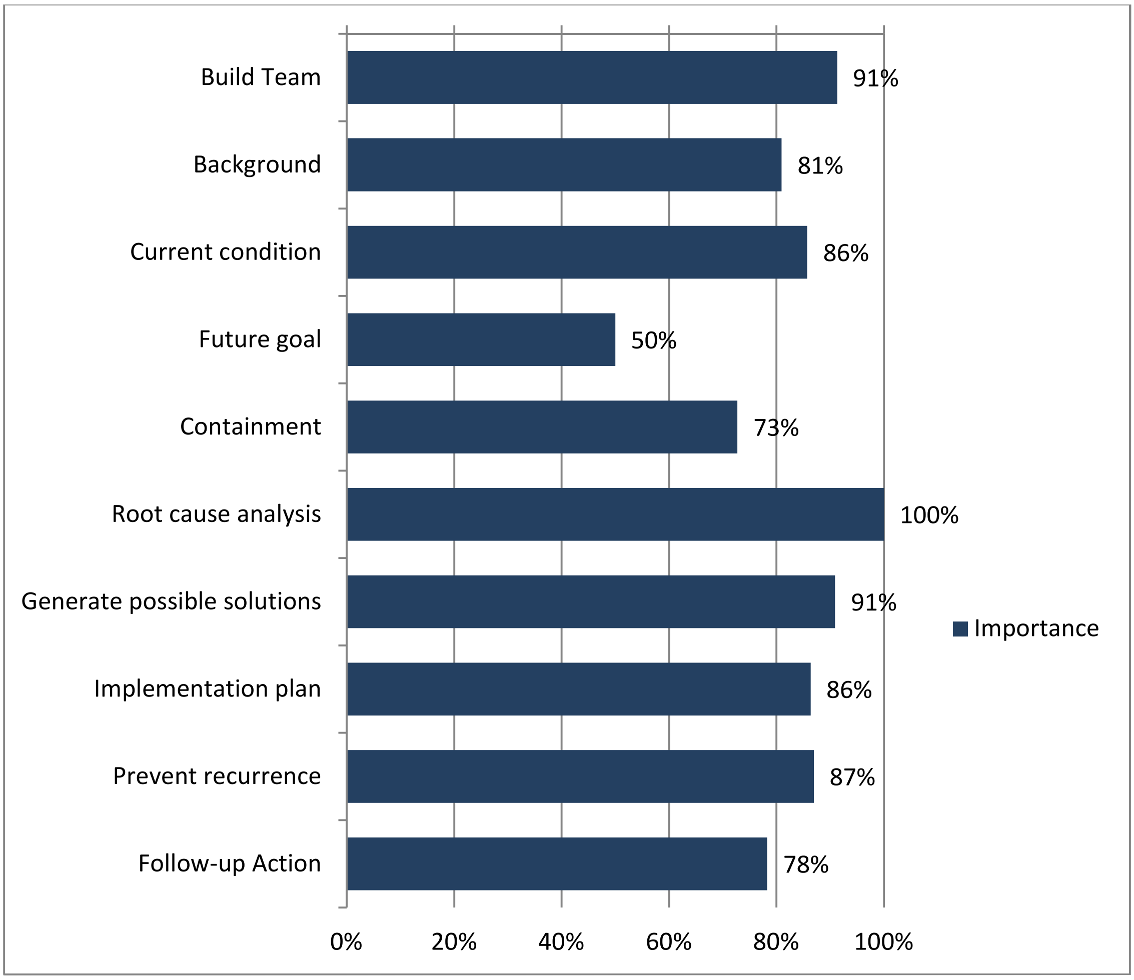


Figure 4-4: Importance of Elements of Problem Solving

Question 3: Which of the following are important activities to be considered during the process of problem solving?

Result: Figure 4-5 shows five activities have been introduced based on the identified features explained in sub-section 3.4.3. These features are represented as the third, seventh, tenth, eleventh and twelfth activities as shown in the figure. The idea is to identify the important of the features to be considered during the process of problem solving. The importance of the five features from the results shows; third activity (100%), seventh activity (78%), tenth activity (50%), eleventh (80%) and twelfth activity (75%). The tenth activity is less than the others due to a lack of understanding and implementation of the learning cycle for continuous improvement, as has been proved by the results shown in Figure 4-1. The results for these five activities clearly indicate that they are important activities to be considered in the process of problem solving for the proposed approach.

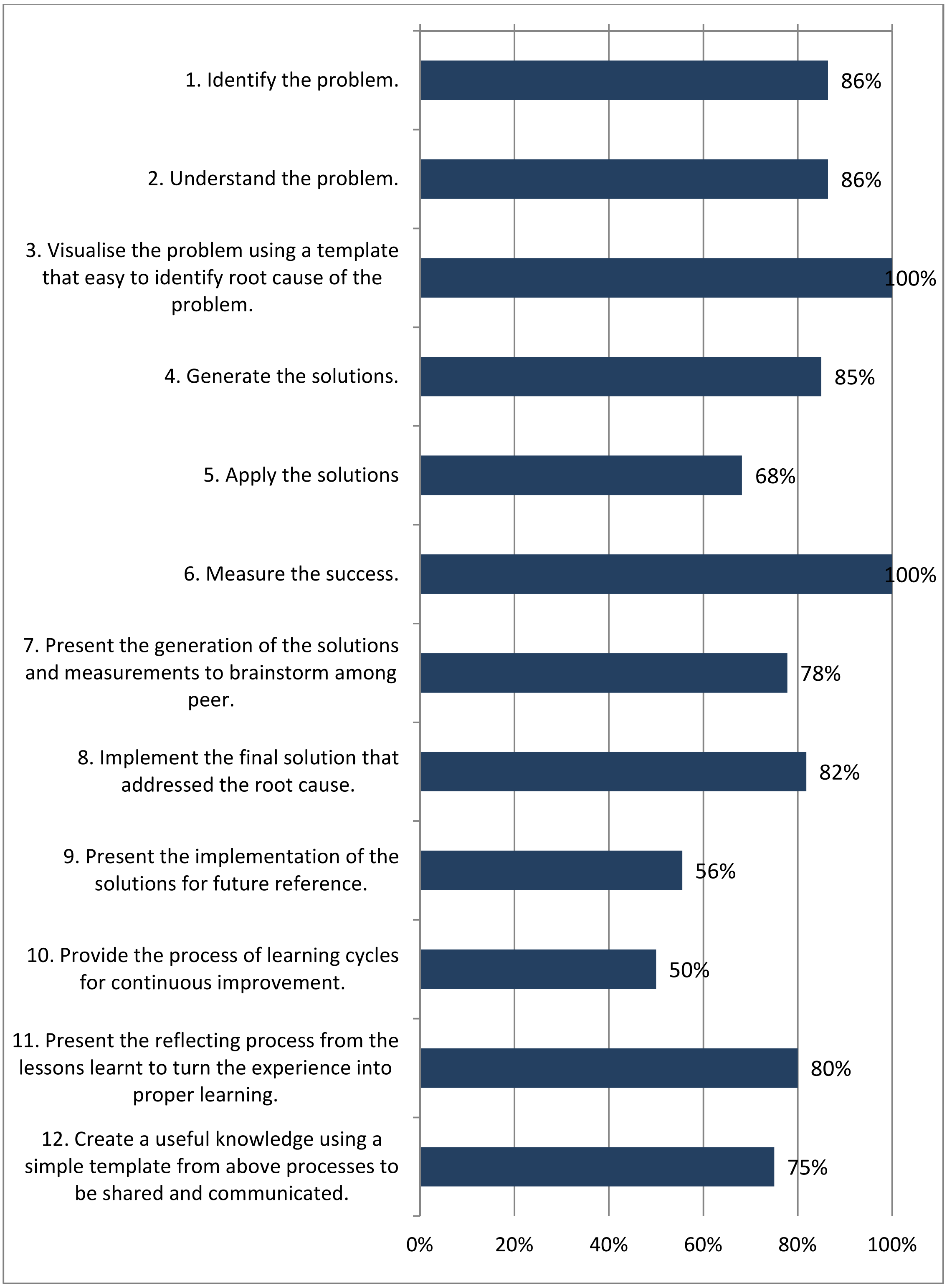


Figure 4-5: Importance of Activities for Process of Problem Solving

c) Knowledge Management Capability

Rationale: The questions for this topic are considered for the current practice of knowledge management capability which has been finalised corresponding to the research as knowledge creation, capture and sharing. Therefore, it is very important to identify the level of application and impact of these three capabilities in order to develop the proposed approach that supports knowledge driven design. Therefore two questions evolved for the topic of knowledge management capability and the results discussed as follows:

Question 1: Do you agree with the following statement?
"The process of solving a problem will create knowledge. The latter is needed to capture and share in a simple manner as a reference for effective decision making in the future".

Result: Figure 4-6 shows most of the respondents strongly agreed with the A3 thinking statement. This statement is reflected in the proposed approach. Therefore, the development of the proposed approach could be existent based on their opinions.

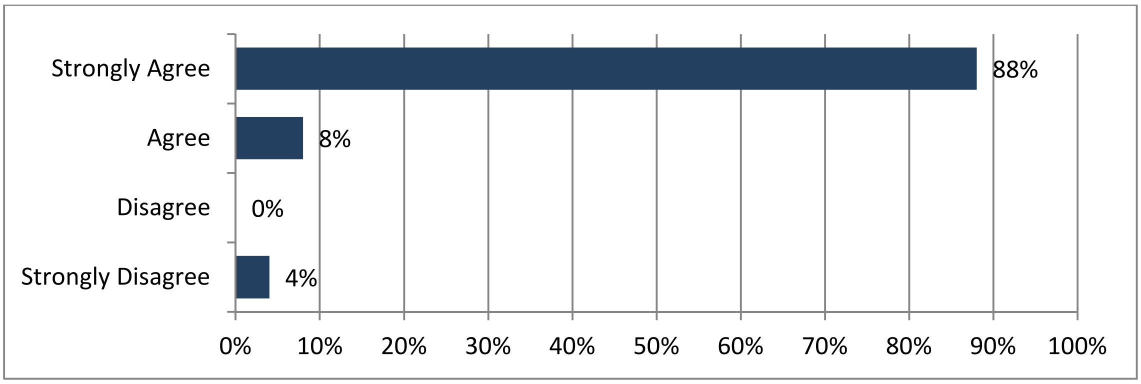


Figure 4-6: Statement of A3 Problem Solving Approach

Question 2: Please rate how satisfied you are with the following practices in your company.

Result: Figure 4-7 shows that more work is required in the process of capturing knowledge from a design solution. More than 40% of the respondents are not satisfied with knowledge sharing from documented knowledge to support decision making.

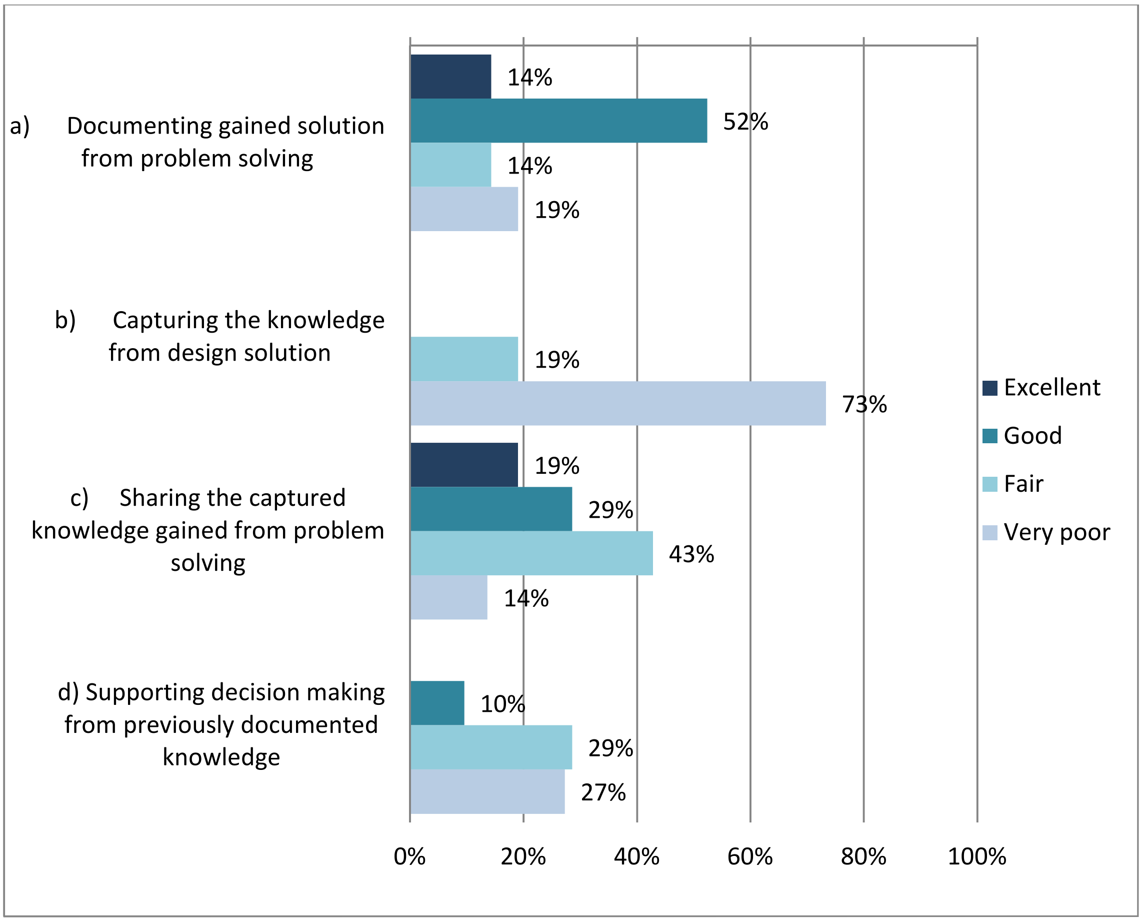


Figure 4-7: The Satisfaction of Knowledge Practices

d) Hypothetical Question - If you are provided with two problem solving approaches (8D and a traditional A3 report) by your company, which one do you think will be easier to guide you to solve a problem and be a good documentation review?

Rationale: This "hypothetical question will generate hypothetical answers that bear little relation to the 'true' answers" (Azevedo et al., 2000). The hypothetical question was conducted by the author during semi-structured interviews by providing an example of 8D and a traditional A3 report as the engineers are quite familiar with these and are implementing the 8D approach widely for quality issues. The objectives of the hypothetical question for this research are presented as follows:

- To introduce and present the traditional A3 report and to challenge the 8D approach in terms of simplicity and visualisation concepts.

- To identify the reason behind their feedback. This has led the author to develop the proposed approach by addressing the gap hence to comply their requirements.

Result: Figure 4-8 shows the results from the hypothetical question where most of the respondents preferred to use a traditional A3 report based on the 'before and after' information of problem solving that stays on one page. However, 30% of engineers preferred to choose the 8D approach as some of the important elements in 8D are not provided in the traditional A3 report which are important for them, namely preventing recurrence and for containment. Therefore, these two elements should be considered for inclusion in a new A3 template.

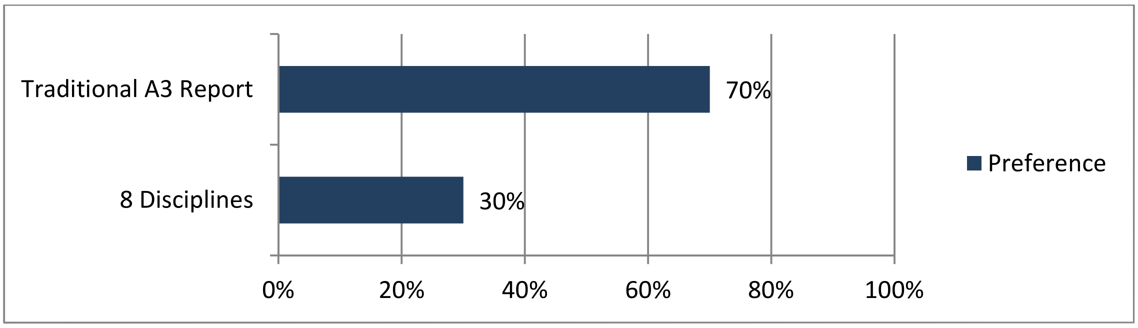


Figure 4-8: Comparison Analysis between A3 and 8D based on Hypothetical Question

Several findings during the semi-structured interviews with the respondents were captured and highlighted as follows;

- Most designers solve the design problem individually and rarely in a group unless the problem is occurring repeatedly or cannot be solved. This has shown that most of the designers are using their personal or tacit knowledge, which is difficult to capture and be transferred to another person. Therefore, a new approach is needed to allow designers to document their tacit knowledge which is then able to be shared within the design team.
- The industries do make efforts to apply learning cycles; however, there is no standard process to guide them especially for the LAMDA and PDCA learning

cycles, where most of the respondents claimed they are implemented but do not apply them formally.

- The design team face challenges in the capturing and sharing of the knowledge created from design solutions, therefore efforts are needed to address these challenges. Some have been identified where they are too time consuming and where it is difficult to extract the captured knowledge.
- The respondents regarded the document template is a good mechanism for knowledge capture and sharing.
- New problem solving approaches and strategies are needed to support the engineers in product design to adopt an efficient knowledge management capability. By considering the knowledge management capability of creation, capture and sharing during problem solving activities, the proposed approach has provided a new A3 template on which these capabilities are adopted in a simple manner.

The following sub-sections explain the detailed collection analyses gathered from document review, direct observation and focus group.

4.3 Detailed Collection and Analyses

The detailed data was collected and analysed in one automotive company in order to develop the A3 thinking approach. This company that collaborated in this research is one of the companies involved in semi-structured interviews and also a LeanPPD consortium as explained in Section 1.7. The data of problem solving approach and process and knowledge management capability were gathered from company's document review, direct observation and focus group and these are explained as follows;

4.3.1 Document Review

The required industrial documents (standard process of product development and design problem solving, As-Is practices of problem solving approaches, reports and documents of the previously documented design solutions and design checklists) have been collected by the author and in collaboration with several researchers in the LeanPPD team. Some of the documents were provided in hard and soft copies. The document review method is the first associated with the company after the literature review, and in-depth analyses were performed in order to identify the gap. The results of the analysis have led the author to understand current scenarios of design problem solving and knowledge management practices in the company, hence build the foundation to develop the new A3 thinking approach. Several findings from the company's document reviewed were captured and highlighted as follows;

- The company has a process to document the important information in design problems, such as identifying problem documentation and solving the problem. However, all these processes could be advanced and of advantage to the company if they can be integrated with the process of capturing the created knowledge, and hence shared within the company.
- 8 Disciplines and Root Cause Analysis approaches are used in quality issues but most of the reports are not fully completed as this requires a lot of work.
- The information regarding each failure, including the title of the failure, product type, root cause and preventing recurring actions developed during problem solving activities was documented but not as standard documentation. Therefore, it is difficult to retrieve the valuable knowledge that was created during the solving of the problems.
- Some efforts are made relating to problem solving documentation but the elements need to be customised in order to be applied to product design.
- There is a design checklist; however it is hardly ever referred to by designers. From the author's overview, this could be because the design checklist is not categorised into different domains which precisely allocate where it is needed, hence more time is required to review it.

4.3.2 Direct Observation

Direct observation was performed during industrial visits at the company, which took from one day to one week per visit by the author and other researchers from the

LeanPPD Cranfield University team. In the first year of this research, the industrial visits were frequently performed in order to identify more information needed for the research foundation and to explore the real experience of problem solving process in terms of performance and mechanism. Several findings from the author's direct observations were captured and highlighted as follows;

- The engineers prefer to use verbal communication to solve the problem and therefore it is not captured or documented.
- During idea brainstorming sessions within the design team and with design experts, the flow of verbally sharing the previous lessons learned is realised and runs smoothly; however the designer seems not to appreciate the need to capture and document those lessons.
- Informal techniques and reports are used to document the solved problems, which means that the structure and the content of this report will depend on the designer's perceptions.

4.3.3 Focus Group

The focus group for this research performed brainstorming activities in the company, involving the author, other researchers from the LeanPPD Cranfield University team and industrial stakeholders. This is aimed to brainstorm a new A3 template to be generated based on the results from documents reviewed and semi-structured interviews. During the brainstorming activity, the author led the conversations with the stakeholders where their perceptions, beliefs, ideas and attitudes towards a new A3 template were captured and recorded. This facilitated the stakeholders in understanding the gaps and realising the limitations of the current problem solving approaches (explained in Section 3.5), hence understanding the relevance and importance of a new A3 template to support decision making in the future. Five people were identified and provided by the company as industrial stakeholders to be members of a focus group, who could relate to the problem solving and knowledge management in product design and development, as shown in Table 4-2.

Stakeholders	Current Roles	Years of Experience
1	Electronic Engineer	9
2	EMC PCB Design Technical Professional	6
3	EMC Application Engineer	7
4	Continuous Improvement Manager	8
5	Continuous Improvement Expert	7

Table 4-2: Details Stakeholders

Several findings from the focus groups were captured and highlighted as follows;

- The stakeholders have realised the relevance of the proposed approach and appreciated the significance of knowledge capture and sharing in problem solving activities for product design.
- The stakeholders have recognised a new A3 template as being a good group communication tool which would allow the flow of brainstorming and sharing of ideas.
- Important and necessary inputs which needed to be clarified and provided for each element have been fixed in a new A3 template. For example, for 'team' element, the necessary inputs are team, author's name, date, title and A3 report number reference.
- The feedback from industrial stakeholders of the relevance of a new A3 template has been captured during the focus group and is presented in Table 4-3. The feedback has been categorised as endorsement and reservation; endorsement refers to the application or benefits of a new A3 template authorised by the company's stakeholders, whereas reservation is the feedback that the author needs to consider and improve for the development of the proposed approach.

Stake-holders	Industrial Judgements of New A3 Template Versions	
	Endorsement	Reservations
1	• The engineers always perform testing to confirm the root cause with temporary solutions, so it will be more helpful to capture this information in a new A3 template. • A new A3 template is also provided for the temporary solution section where this is sometimes necessary because it's cheaper and quicker. • It will be good to clarify the knowledge.	• A new A3 report is interesting because of being one-page; however, does that A3LAMDA report have enough space? • Who will be responsible for transferring knowledge from a new A3 report to the design checklist?
2	• The flow of the elements in a new A3 template is quite logical and makes sense, covers all the processes of problem solving, and in addition, the reflection of capturing knowledge. And, if a new A3 format could have a link to other files that would be useful. • The reflection section is the most important part where it will be easy to pull out the knowledge into the design checklist. • It is very interesting to have the template; currently when facing complex failures, they used to attach many documents, but now it will be restricted to A3 size paper. Agree with this idea. • At the top level, this kind of classification on root causes types is pretty good. • Design rules and design recommendation structured in the reflection section, will help to categorise the knowledge into different parts of the checklist. • In the reflection section; 'where is the knowledge needed?' is the most important part.	• It would be good if the tool to transfer the knowledge from the A3LAMDA into the checklist were automatic. • The necessity of a picture in a new A3 report may depend on different products. The point is if the picture will provide useful information. If the way to search the related product picture and put in an A3 report is convenient, it will not be able to encourage the engineer to use a new A3 template. • The picture put into a new A3 template would be restricted by the size, sometimes we need a big picture; could a new A3 template have the function to zoom in a big picture. • If I'm struggling to find the pictures of the product, I will not do this new template. • A new A3 template should be developed in Java.
3	• A report format is better with the headings you've used in a new A3 template. • The effectiveness of the knowledge created from a new A3 template would partly depend on the expertise of the engineer who is filling it in. That is why you are developing these elements to narrow down the content, and try to make it more objective. • The containment in proposed solutions is a good idea.	• Unfortunately I found the new A3 report very difficult to fill in because there was so much duplication of the same information and the constriction of the space for inputting a valid explanation and the associated diagrams. • The reflection section is difficult to understand and to fill-up if somebody had not explained it to me.

4	• I like the link between 'what is before' and 'what is after' in a new A3 template. • The visualization of the design before modification and after modification is good. And it is good to provide a space where the designer can write the design reference. • The flow in the new A3 template is good. • The link between the amount of root cause analysis and proposed solutions is good. Each identified root cause must be provided for at least one of the proposed solutions. It is also good if the numbers in root causes analysis can be generated in the proposed solutions where it can encourage the designers to be aware and hence provide solutions for each of the identified causes. • The new A3 template enables the future designer to easily trace the failure and how the solution is delivered and that will make them break it down into a new understanding.	• How to insert a picture into a new A3 template in 4-5 seconds. Without pictures in a new A3 template, it will be no different from other approaches.
5	• Yes, the new A3 template is quite good. • Yes, I am agreed that knowledge could be shared if we place the new A3 report on the coffee machine. • The question in the 'prevent recurrence' element is interesting; 'has the solution affected other products or processes, which is an advantage in problem solving for product development. Also 'has the solution been standardized?' is the interesting part. • The new A3 template is solving the problem by capturing and documenting the people knowledge.	
1,2, 3,4 & 5	• The new A3 template should be a good communication tool rather than solving the problem. That is the beauty of the new A3 template which is that all the information stays at the front. • They agreed with the process to solve a problem by documentation of the failure with a proper template, and a new A3 template. However, there is a specified way in industry to follow in order to solve problems. Sometimes EMC engineers just hands on to solve EMC problems in very different way.	• The linkage between the elements in a new A3 template is very good if it can conduct automatically.

Table 4-3: Stakeholders Feedbacks on Development of a New A3 Template

The findings gathered from detailed data collection of the company's document reviews, direct observation and focus group have led the author to develop a final version of a new A3 template and a new approach to solve problems in product design. The process was also developed based on the new A3 template hence guide designers to provide useful knowledge for future design reference. The different stages of designing and validating a new A3 template, thus three versions were generated and explained as follows;

1. First Version – The first version of a new A3 template was designed and generated based on the reviewed literature and as illustrated in Table 3-6, consists of ten elements. Then, it was compared to the results gained from the semi-structured interviews as follows:

- 'Future goal' is the lowest importance based on the results of the questionnaire; therefore it is not structured in a new A3 template as shown in Figure 4-4.
- The 'containment' is a second lowest importance from the results of the questionnaire (see Figure 4-4) but based on the analysis from the hypothetical question as shown in Figure 4-8, 'containment' is one of the important elements in the 8D approach which make the respondents prefer to choose 8D. Although 'containment' is not an element for a new A3 template, it was considered as an input in a 'proposed solution' element.
- 'Follow-up action' comprises less than 80% in the results of the questionnaire, but from the documents reviewed, their current problem solving approach (8D) is also concerned with the follow-up action. In order to determine the importance of 'follow-up action', it was structured as the eighth element in a new A3 template.
- Finally only eight elements: 1) team, 2) background, 3) current condition, 4) root cause analysis, 5) proposed solutions, 6) implementation plan, 7) prevent recurrence, 8) follow-up action. But the author added 3 elements for reflection (What-So what-Now what) as explained in Section 5.4.

In order to have feedback regarding this version from the industrial stakeholders, the author and one EMC stakeholder documented a current design problem using the first version of a new A3 template. The first version of a new A3 template and report are provided in Appendix 6 and Appendix 7.

2. Second Version – The second version was designed and generated, according to the analysis from the first version of a new A3 template and the report. However, the reflection section became the priority in generating the second version. The differences between the first and second versions are explained as follows:

- The 'follow-up action' was eliminated from the second version as its relevance is low. Therefore, seven elements and three for reflection were structured for the second version.
- The so what and now what questions at the reflection section in a second version of A3 template have been replaced and modified compared to the first version. For example, the question of *'where the knowledge created'* has been removed and replaced with *'where is the knowledge needed'*.
- The inputs for each element have been finalized. However, these could be modified based on the company's requirements.

In order to have feedback from the industrial stakeholders about this version, the author and two of the company's stakeholders solved and documented the current design problems. Therefore, a second version of a new A3 template is shown in Appendix 8 and two examples of a new A3 report are shown in Appendix 9 and Appendix 10.

3. Third Version – The final version of a new A3 template is based on the modification for reflection section only, which are contained in the last three elements in a new A3 template, namely;

- 8) What – What is the knowledge?
- 9) So what? – How can this knowledge be applied?
- 10) Now what? – Where is this knowledge needed?

Compared to the second version of the A3LAMDA template, the table of lessons learned has been provided into element of 'What' before the generation of design rule and recommendation. This will guide the designers to turn their new lessons throughout problem solving activities into useful knowledge. The final version of a new A3 template is shown and explained in Chapter 5.

4.4 Chapter Summary

This chapter has presented the industrial perspectives of the problem solving approaches and knowledge management capability within the automotive industrial sector. The perspectives have been captured through a semi-structured interview and close-ended questionnaire within 25 respondents from two companies. In order to have more detailed information and to shape the development of a new approach, the methods of document review, direct observation and focus group were performed in a company. The company for data collection which is one of the consortiums in the LeanPPD project, has fully participated in this research. The key findings from all the data collection methods are summarised and explained which has led to the generation of three versions of a new A3 template, hence the endorsements and reservations from the stakeholders have been captured. The following chapter presents the development of a novel A3 thinking as a problem solving approach for product design.

Chapter 5

5 DEVELOPMENT OF A NOVEL A3 THINKING APPROACH

5.1 Introduction

This chapter presents the development of a novel A3 thinking approach to support knowledge driven design by providing a new A3 template as an approach to solving problems in product design. The A3 thinking approach was developed by addressing the limitations of the problem solving approaches gained from the reviewed literature and stemmed from the requirements of the collaborative company. The remainder of this chapter introduces the definition of a developed approach in Section 5.2. A new A3 template was divided into two sections. The first section, namely about problem solving and referred to as knowledge creation, is described in Section 5.3. The reflection practice which has been adopted to capture the created knowledge in a new A3 template is explained in Section 5.4. In Section 5.5 presents knowledge capture and sharing in depth. The contribution of the failure documentation template is introduced in Section 5.6 in order to capture the correct and necessary data of the identified design problems. The process of using the A3 thinking approach is described in Section 5.7. As an alternative, the author has developed a new A3 template in Microsoft Word Developer to speed up the process of completing and documenting a template and is presented in Section 5.8. Finally, the chapter summary is presented in section 5.9. Figure 5-1 illustrates the structure of this chapter.

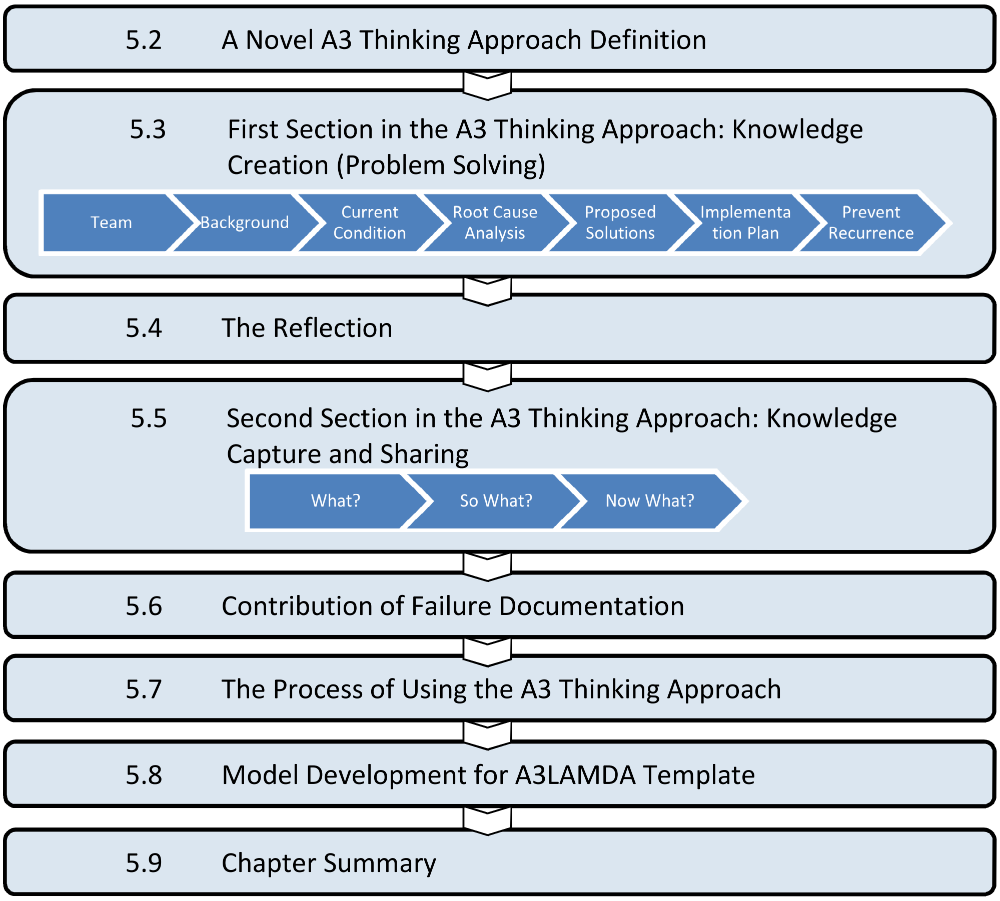


Figure 5-1: Structure of Chapter 5

5.2 A Novel A3 Thinking Approach Definition

The identified limitations, as explained in Section 3.5, have shown that the current problem solving approaches do not fulfil the capability of knowledge management. This is due to the knowledge created from the problem solving activities not being well captured and documented. Table 5-1 presents the summary of the limitations based on the five identified features as explained in sub-section 3.4.3. The actions column of Table 5-1 shows short term actions based on the defined features. The idea is to encourage the designers to perform those actions by visualising the problem in order to create useful knowledge efficiently by using a new A3 template. The designers, who integrated all those actions from visualising to creating, are considered as having reached an appropriate solution, hence supporting knowledge-driven design.

Features	Problem Solving Approaches						Actions
a) Visualise the necessary process and information to address the problem	A3	8D	PAF	RCA	5 Whys	**A3 thinking Approach WILL cover these features**	Visualising
b) Present the generation and implementation of the solutions							Solving
c) Provide the process of the learning cycle for knowledge creation							Learning
d) Present reflections on lessons learned							Reflecting
e) Create useful knowledge concisely from those actions to be shared and communicated.							Creating

Table 5-1: Features and Comparison Approaches

Kruger and Cross (2006) in their study of the design process, define knowledge-driven design as being when a designer concentrates on using previous, structured, personal knowledge, and builds a solution on the foundation of that knowledge. However, in this research, the author has defined that knowledge-driven design is the knowledge gathered from the integrated actions of visualising, solving, learning, reflecting and creating (as shown in Table 5-1) by using a new A3 template. This supports the key principles of knowledge based environment and continuous improvements in the LeanPPD model as explained in Section 1.6. Figure 5-2 illustrates a cycle of knowledge-driven design on the integration of the aforementioned actions.

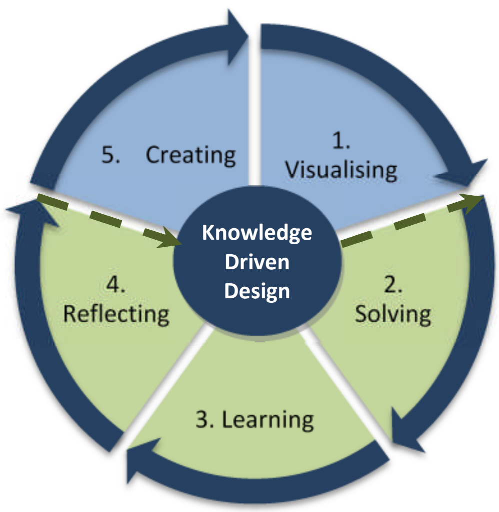


Figure 5-2: A Cycle of Knowledge-Driven Design

Therefore, based on the research findings in prior chapters, the author has defined the new A3 thinking approach as the one providing a new A3 template as a tool in design problem solving to aid the generation of knowledge-driven design to support decision making. The latter gathered from the integrated actions of visualising, solving, learning, reflecting and creating. The second, third and fourth (solving-learning-reflecting) actions coloured in green in Figure 5-2, are considered to be repetitive actions as the process may return to a previous action if the solution is not addressing the problem as the designers expected, or if it failed. However, this experiential failure in learning supports designers in their ability to extract meaningful knowledge and inspires them to alter knowledge (Madsen and Desai, 2010) hence it is vital for it to be captured and documented. Details in Figure 5-2 are further described in Table 5-2.

Integrated Actions	Descriptions on Actions
1. Visualising	• This action will use a new A3 template provided from the A3 thinking approach to visualise the problem, solution and knowledge captured.
2. Solving	• This action will solve the problem by following the elements provided by the A3 thinking approach sequentially structured and illustrated on a new A3 template.
3. Learning	• This action based on the LAMDA learning cycle will guide its users on how to solve a design problem and to emphasize knowledge creation.
4. Reflecting	• This action is based on the term 'reflection' which means to support the problem solvers in turning their experience or tacit understanding both during and after solving the problems into proper learning.
5. Creating	• This action will use a new A3 report to represent the provision of the useful knowledge gained from the above actions to be shared and communicated.

Table 5-2: Actions Needed in the A3 Thinking Approach to Support Knowledge Driven Design

In brief, the knowledge-driven design based on the A3 thinking approach enables designers to obtain a high level of understanding of the useful knowledge captured and documented in a new A3 report, which can be used as a reference to aid decision making and to prevent design problems in the future project(s). This is to bridge the gap mentioned by Ward (2007) that '*Almost all defective projects (projects that miss the market, have manufacturing cost or quality problems, or budget and time overruns) result from not having the right knowledge in the right place at the right time. Therefore, usable knowledge is the basic value created during product development.*

Usable knowledge prevents defects, excites customers, and creates a profitable operational value stream which is the goal of product development'. The most important foundation of the A3 thinking approach is to develop a new A3 template, hereafter referred to as an A3LAMDA template, in order to differentiate it from the traditional A3 template and was developed as a tool to solve problems in product design. The name is given as 'A3LAMDA' because the LAMDA learning cycle was chosen to be used instead of PDCA in the traditional A3 report. Figure 5-3 shows the final version of the A3LAMDA template gathered after two versions have been generated, as explained in 4.3.3. Many discussions and meetings with the engineers and people involved in problem solving were performed in order to generate and finalise the A3LAMDA template. The A3LAMDA template consists of ten elements sequentially structured and located into two sections namely: knowledge creation and capture. The details of a new A3LAMDA template are shown in Figure 5-4.

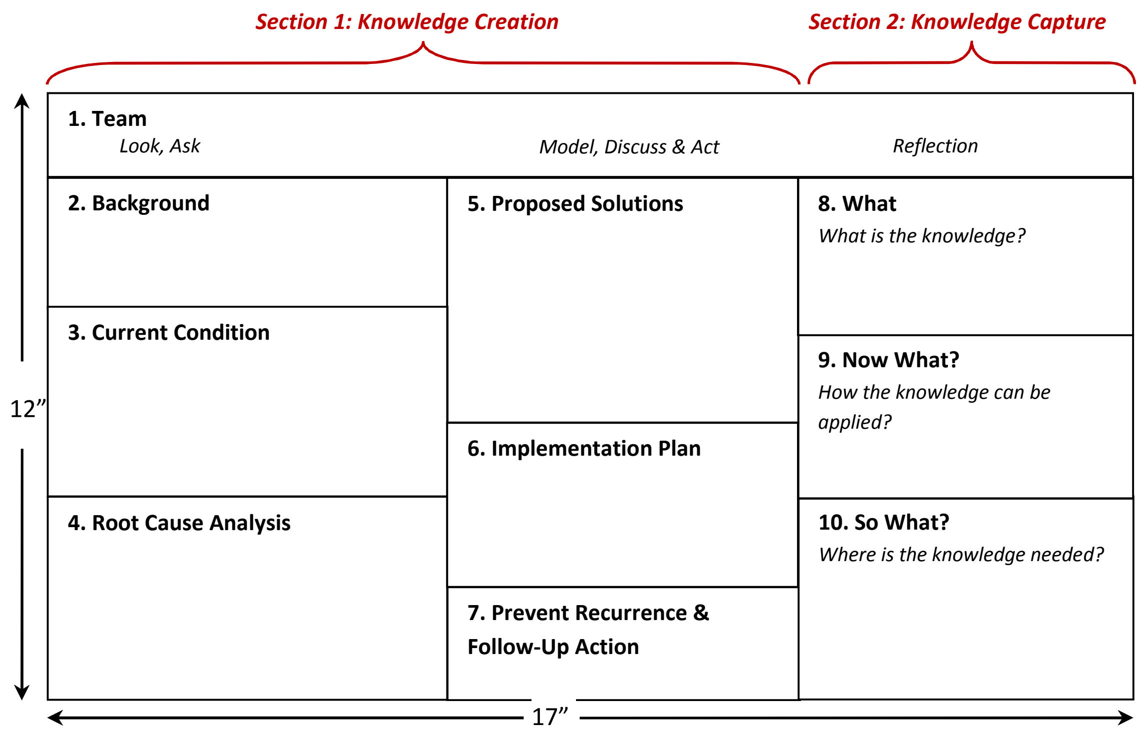


Figure 5-3: The New A3LAMDA Template

The following section explains in detail each section of the A3LAMDA template provided for the A3 thinking approach.

1. Team :	Author:	Date:	Title:	A3 Report No.:
Look – Ask		*Model – Discuss – Act*		*Reflections*

2. Background

Product Type	
Product Name	
Product Code	
Software No.	
PCB No.	
Serial No. (S/N)	
Customer Spec.	
Other Information:	

Product Picture

3. Current Condition

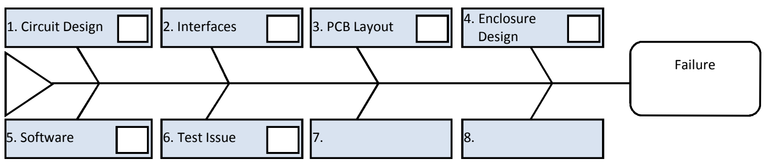
Test Request No.		Functional Status	
Test report No.		Functional Performance Class	
Test Type		Occurrence	
Other Information			

Description of Failure:

Failure Test Diagram

4. Root Cause Analysis

Any Diagnosis:



No.	Causes	Reason

5. Proposed Solutions

No	Solutions	Confirmation			Type of Solutions	
		N/Eff	S/Eff	V/ Eff	Cont	Perm

BEFORE		PROPOSE	
	Before Modification Design /schematic Picture		After Modification Design /schematic Picture
	Design Ref. No.:		Design Ref. No.:

6. Implementation Plan

No.	Tasks	Actions to Implement Proposed Solutions	Responsibility & Duration

Result:

Result Test Diagram

7. Prevent Recurrence & Follow-up Action

Questions for Prevent Recurrence	Y	N	Descriptions & Actions to Prevent Recurrence
1. Does the solution impact other EMC tests?			
2. Any consequences of possible solution cause to other products?			

8. What?

Lessons Learned

9. So What?

Type of Knowledge : Design Rule (DR)/ Recommendation (Rec)	Design Issues: Circuit Design	PCB Layout	Interfaces	Software	Enclosure Design	Other
DR 1 Rec 1						
DR 2 Rec 2						
DR 3 Rec 3						

10. Now What?

DR / Red	Function	Activity

Figure 5-4: Detailed of a New A3LAMDA Template

5.3 Knowledge Creation by A3LAMDA Template

This first section in the A3LAMDA template, called knowledge creation, consists of the following seven elements customised from the limitations within problem solving approaches gathered from Chapters 3 and 4: (1) Team, (2) Background, (3) Current condition, (4) Root cause analysis, (5) Proposed solutions, (6) Implementation plan, and (7) Prevent recurrence and Follow-up actions, as shown in Figure 5-3. This section will encourage designers to perform the first (visualising), second (solving) and third (learning) actions in order to support knowledge-driven design, as shown in Figure 5-2. Visualising the necessary information and solving the problem using the LAMDA learning cycle will provide efficient, useful knowledge to support design decision making for the future project in a knowledge-rich environment. However, within this section, designers are also encouraged to reflect on their actions before reaching the solution and representing it in the appropriate columns as a reflection. The following explains the elements in the A3LAMDA template. Also, the author provides each of these elements with the recommended tools that need to be considered in order to fulfil each of the elements.

1. **<u>Team</u>** – Build a team which involves responsible people who are involved in the design problem and process, the A3LAMDA template's author, date, title, and A3LAMDA report reference number.
   Recommended Tools: No tool is needed.

2. **<u>Background</u>** – Details of the product or process such as product type, name and code, software number, printed circuit board number, serial number, and customer specification. The A3LAMDA author can also add the goal of the problem solving or current state of the problem.
   Recommended Tools: Texts, table, diagram, graphs, bullet points and sketches.

3. **<u>Current Condition</u>** – Identify the current condition based on 'Gemba' (from the Japanese for place where work takes place) (Womack and Shook, 2011) then

document and validate the observations very concisely and effectively to understand the real problem. The inputs of this element should be test request number, test type, functional status, performance class and occurrence. In addition, describe the effect of the failure, problem symptoms, clarify the fault description, attach and visualise the necessary data, confirm the design problem.

Recommended Tools: Texts, tables, diagrams, graphs, bullets, sketches, tally sheets, current-state maps, histograms, scatter diagram, flowcharts and check sheets.

4. **Root Cause Analysis** – Consider the most useful approach to identify/explain the root cause for the current state visually. Diagnose the problem and identify types of design and the defect. Review all the analysis and discuss the results by sequentially listing the underlying causes of the problem. All these activities will discover the potential root causes. Explain the reasons for each cause.

   Recommended Tools: Brainstorming, texts, table, diagram, graph, bullets, sketches, tree diagram, failure mode and effect analysis (FMEA), flowcharts, causal chains, tables, Pareto chart, scatter diagrams, problem impact matrix, cause and effect fishbone, check sheets, histograms and charts.

5. **Proposed solutions** – Explore a set of potential solutions that directly address the root causes. Apply the solutions and compare their effectiveness and confirm either that they are long term or containment solutions. Make sure the solutions address the root cause of the problem.

   Recommended Tools: Table, design rules, previous A3LAMDA reports, process flow, diagrams, sketches, graphs, charts, future-state map and evaluation matrix, brainstorming, interviewing, check sheets, criteria rating forms, weighted volume, the evaluation and review technique (PERT) chart and theory of inventive problem solving (TRIZ).

6. **Implementation Plan** – Implement the corrective actions by highlighting the main actions and outcome, sequence, resources and support required, persons, and deadline; also control and monitor the potential effect.
   Recommended Tools: Gantt chart (to display actions, steps, outcomes, timelines, roles) graphs and tables, flowcharts, check sheets and control plan.

7. **Prevent Recurrence and Follow-up Action** – Prevent problem recurrence by a) identifying the solution that could impact on other product and process designs, and b) discovering any consequences that possible solutions may cause to other products and processes.
   Recommended Tools: Provide right knowledge from previous design solutions and Failure mode and effect analysis (FMEA).

During the first section, the designer will identify and solve the design problem guides by LAMDA as a knowledge creation cycle. The created knowledge throughout the problem solving activities needs to be captured; therefore the A3LAMDA template has been provided by the author with a second section which is 'reflection'. The next section explains the definitions and purpose of reflection in greater depth before describing the application of reflection as a second section in the A3LAMDA template in Section 5.5.

5.4 Reflection

Turning a solution into learning, also called the reflection, has been commonly used in education. Therefore, some key authors have been selected and their perspectives of reflection are defined as follows:

a) Razzaghi and Ramirez (2005) – "Products can be considered as the reflection of designers' desire and preferences."
b) Reymen and Hammer (2002) – "Reflection is vital in any learning process; Reflection can help designers to learn from their experiences, help them to become more conscious about the performed activities, learn which activities

were not successful for reaching the design goal, and the actions that influence the design activities. Summarising, reflection in a design process can contribute to a steeper learning curve of designers, to a smoother design process, and to an improved product being designed."

c) Daudelin (1996) – "The reflection is the process of stepping back from an experience to ponder, carefully and persistently, its meaning to the self through the development of inferences; learning is the creation of meaning from the past or current events that serves as a guide for future behaviour." One of the approaches for increasing the learning power of the reflection is the posing and answering of questions.

A 'reflection' is the term used in education learning tools to clarify knowledge (Daudelin, 1996). There are two types of reflection defined by Schon (1987), reflection in action (RIA) and reflection on action (ROA). The former is a reflective practice conducted during the problem solving (present tense) whilst the latter is solved after the problem (past tense), and provides the focus for this research. However, Alsop and Ryan (1996) define a further category of reflection: reflection in the future tense. At present, this is not to be considered, as the idea for this research is to capture and share the created knowledge only during and after solving the design problem. The use of reflection structured within the A3LAMDA template is to guide and support the designers or design team in verbalising and documenting either their present or previous lessons learned. Hence, the created knowledge will be applied efficiently; for example, why it is important, who and when should use the created knowledge. York-Barr et al. (2006) has identified potential benefits of the reflection practice, such as continuous learning for experienced engineers, bridges theory and practice, consideration of multiple perspectives, productive engagement of conflict, knowledge for immediate action, embedded formative assessment and individual and collective efficacy. Table 5-3 shows the reflection practices. The Borton practice was selected as it is simple to be structured in the A3LAMDA template hence to be used in product design problem solving.

Authors	The Reflection Practices
Borton (1970)	What? – So What? – Now What?
Kolb (1984)	Concrete experience – Observations and reflections – Formation of abstract concepts and generalizations – Testing implications of concepts in new situations
Atkins and Murphy (1994)	Awareness of uncomfortable feelings and thoughts – Describes the situation including thoughts and feelings – Analyzes feelings and knowledge relevant to the situation – Evaluates the relevance of knowledge – Identifies any learning which has occurred
Johns (2000)	Description – Reflection – Influencing factors – Alternative Strategies – Learning

Table 5-3: Type Reflection Practices

Table 5-4 explains Borton's reflection practice and the recommended reflection based on questions (Daudelin, 1996). Each of the phases in Borton's reflection practice includes several questions by Borton that can encourage and help practitioners to verbalise their tacit understanding, hence capturing the created knowledge. However, for this research, only one question is developed and tailored at each of the phases in Borton's reflection practice, as shown in the next section.

Bortons' Reflection Practice		
What?	**So What?**	**Now What?**
Example: - What was the problem? - What can I conclude from the solution? Bad or good about the experience.	Example: - What did I learn? -What is the consequence of the solution?	Example: - Now, what do I need to do? -What is the best improvement?

Table 5-4: The Details of Borton's Reflection Practice (Borton, 1970)

This section explained the first section, which includes the first, second and third actions: visualising, solving and learning. The second section in the A3 thinking approach includes two actions: reflecting and creating which are explained in the following section.

5.5 Knowledge Capture and Sharing by A3LAMDA Report

The second section in the A3LAMDA template will be performed in the right hand column of a template as shown in Figure 5-3. Regarding the two sides of Figure 5-3, the left side shows that the first section is accomplished where the knowledge is created from the verified solution (Elements no. 1-7). The completion of the first section of knowledge creation in the A3LAMDA template, has led to the implementation in a second section of knowledge capture and sharing. The second section focuses on the fourth and fifth integrated actions – 'Reflecting' and 'Creating' as explained in Table 5-2. The final integrated action – Creating – is explained at the end of this section to create the useful knowledge captured in the reflection section, hence to be compiled in the database as a design reference for future design project. This research has adopted the Borton's model of reflection based on the questions of what, so what and now what (Borton, 1970) in the A3LAMDA template. The following explains the details of the identified question in each section of Borton's reflection practices structured in the A3LAMDA template:

a) What? – What is the knowledge?

   This is where the lessons learned will be captured and documented. In order to represent and capture the lessons learned, the following must be considered:

   - Reflection in action (RIA): Whilst solving the design problem. This is the nature of tacit knowledge where sometimes it is automatically developed, i.e. when the designers start solving the problem or during brainstorming activity within the design team.
   - Reflection on action (ROA): After solving the design problem. This is an activity to capture the lessons learned based on the verified solution

b) So What? – How can the knowledge be applied?

   Knowledge is created through learning in the design problem solving process. The designers need to choose the lessons learned that have been captured in the 'What?' element, i.e. considered as important for future design reference. Then, it is necessary for the A3LAMDA report's author to formulate this as a design rule or recommendation. The design rule is defined as an important reference that is highly recommended when considering decision making for the future whilst the design recommendation is defined as a general advice or suggestion based on the designers' experience. In order to apply this element, the author has provided a table structured with two columns entitled design rules (DR) or design recommendations (Rec) and types of EMC design issues as shown in Table 5-5. In the first column, the designer has to formulate the lessons learned to the design rule or design recommendation, then choose and link which design issues are related in the second column. The idea of the second column is to speed up the process in exploring the DR and Rec for the specific design issues, as identified in a root cause analysis element in the future.

	Design Issues					
Design Rule (DR)/ Recommendation (Rec)	**Circuit Design**	**PCB Layout**	**Interfaces**	**Software**	**Enclosure Design**	**Other**
DR 1 / Rec 1						
DR 2 / Rec 2						

Table 5-5: Ninth Element in the A3LAMDA Template

c) Now What? – Where the knowledge is needed?

The designers need to discover and identify which functions and activities in the product development where the design rules or design recommendation will be needed. The idea is to provide useful knowledge for the right people and in the right place.

The final integrated action in the A3 thinking approach to support knowledge driven design is creating. As explained in Table 5-2, creating is an action where the designer creates useful knowledge gained from prior actions of visualising, solving, learning and reflecting. This useful knowledge is derived from the design rules and design recommendations in the reflection section and should be stored in a knowledge database as a design reference. This useful knowledge can be a design statement or design question checklist and examples of both are shown in Table 5-6.

Design Issues	Design Statement Checklist (DSC)	Design Question Checklist (DQC)
1.Circuit Design	a) Use series R buffering on all high-speed clock and data lines. b) Do not leave unused IC input pins floating: tie them to 0V or V_{CC}	a) Have the analogue signal bandwidths been minimized? b) Has the dynamic range of analogue signal paths been maximized?
2.PCB Layout	a) Minimize the surface areas of nodes with high dv/dt. b) Before routing begins, identify and label sensitive circuits.	a) Have the surface areas of nodes with high dv/dt been minimized? b) Have the component placements been checked to ensure there are no unnecessarily long track routes?
3. Interfaces • Cables	a) Choose RF-screened cables if the wanted signal cannot be properly filtered. b) Ensure that cable screens are properly terminated to the connector backshell; avoid pigtails.	a) Have the signal and power cables been segregated and do they avoid parallel runs? b) Have properly designed looms, ribbons or flexis for internal wiring been used in order to avoid loose wires and bundles?
• Grounding	a) Consider the ground system as a return current path, not just as an 0V reference. b) Avoid common ground impedances for different circuits.	a) Is the bonding of screens, connectors, filters and enclosure panels metal-to-metal? b) Has the interface ground area for decoupling and filtering been provided?
• Filters	a) Ensure a defined ground return for each filter. b) Assume that a supply filter is needed: design the filter for the application.	a) Is there a defined ground return for each filter? b) Has the filtering to interference sources directly to the terminal been applied?

Table 5-6: Design Issues and Design Checklists (Williams, 2007)

This table shows the design issues which consist of circuits, PCB layout, and interfaces, such as cables, grounding and filters. Each of the design issues are provided with alternative design reference either as Design Statement Checklist or Design Question Checklist. The Design Statement Checklist is based on the Electromagnetic Compatibility (EMC) design rules provided by Williams (2007) whereas the Design Question Checklist was generated by the author of this thesis based on Williams' EMC design rules. This research will provide useful knowledge not based on the Design Question Checklist but on the Design Statement Checklist as it will be captured directly from the design rules or design recommendations in the reflection section after confirmation from knowledge experts in product design. However, expert knowledge will not be further explained in this thesis as the LeanKLC (Maksimovic, 2013) will be focusing on this. In addition, current design checklist in the company is based on statements instead of questions. The next section explains the contribution of the failure documentation template for the A3 thinking approach.

5.6 Contribution of the Failure Documentation Template

The ‘failure documentation’ developed by one of the LeanPPD team members aims to provide integration with the traditional A3 template in design problem solving (Zhu, 2012) as shown in Figure 1-1. The failure documentation has been utilised as part of the A3 thinking approach in order to capture necessary information and data from the person who identified/found the design problems, and hence to transform this into an A3LAMDA template. This can not only eliminate misunderstandings and incorrect perceptions of the identified problem but can also speed up the process of completing the A3LAMDA template. The failure documentation template as shown in Table 5-7 is based on the failure modes and effect analysis (FMEA) template which includes the following key elements; a) Title, b) function, c) failure mode, d) risk priority number and e) Description of failure.

<table>
<tr><th colspan="6">Failure Documentation Template</th></tr>
<tr><td colspan="6">a) Title:</td></tr>
<tr><td colspan="2">b) Function (Fc)</td><td colspan="2">c) Failure Mode (FM)</td><td colspan="2">d) Risk Priority Number (RPN)</td></tr>
<tr><td>Product Type</td><td></td><td>Test Type</td><td></td><td>Functional Status
(For Immunity only)</td><td></td></tr>
<tr><td>Product Name</td><td></td><td>Customer Spec.</td><td></td><td>Functional Performance Class
(For Immunity only)</td><td></td></tr>
<tr><td>Product Code</td><td></td><td>Test Request No.</td><td></td><td>Occurrence</td><td></td></tr>
<tr><td>Software Number</td><td></td><td rowspan="3">Other Information</td><td colspan="3" rowspan="3"></td></tr>
<tr><td>Serial. No. (S/N)</td><td></td></tr>
<tr><td>Printed Circuit Board No.</td><td></td></tr>
<tr><td colspan="6">e) Description of failure:</td></tr>
</table>

Table 5-7: Failure Documentation Template

However, this has been modified and new sub-elements have been added in order to customise the template as a result of this research focus as follows:-

a) Title: will describe the appropriate headings referring to the product, design test, date, year and client.
b) Function (Fc): Product Type, Name & Code, Software, Serial and Printed Circuit Board (PCB) No.
c) Failure Mode (FM): Test Type, Customer Specification, Test Request No. and any other information.
d) Risk Priority Number (RPN): Functional Status, Functional Performance Class and Occurrence where each of the parameters is according to a customer's specification.
e) Description of failure: will describe the observations made during the EMC Test or as a 'One Description'.

The previous sections have explained the definition of the A3 thinking approach and development of the A3LAMDA template. Two sections for knowledge creation and capture and also ten provided elements were described in detail. These have led the author to develop the process of using the new A3 thinking approach based on the A3LAMDA template, which is explained in the next section, as a guideline for practitioners to solve problems and hence generate useful knowledge in product design.

5.7 The Process of Using the A3 Thinking Approach

This section explains the process of using the A3 thinking approach to solve design problems in product design. This is to support and guide the product designers, engineers, problem solvers or anyone else who wants to implement the A3 thinking approach effectively and sufficiently as a product design problem solving approach by utilising the A3LAMDA template. The scenarios of using the A3 thinking approach are as follows:

1. Design problem solving before prototype testing
2. Design problem solving after prototype testing
3. Generation of a new idea during product design & development

4. Documentation for solved design problems
5. Knowledge communication tool during product design development
6. Capturing the created knowledge as a result of the new design that was passed the first time

The process of using the A3 thinking approach explained in this section only focuses on the first and second scenarios as both are involved completely in problem solving activities from identifiying the design problem until verifying the solution and capturing the created knowledge; however, the remaining scenarios are only a part of these activities. Figure 5-5 is a diagram for the process flow of using the A3 thinking approach which contains ten stages, also consists of important templates in the process of the A3 thinking approach (failure documentation and A3LAMDA) and the knowledge database are represented in yellow. Each of them is explained as follows:

a) Failure Documentation template (as shown in Table 5-7) – to document the design problems. The information and data written in the failure documentation template are divided into five categories: title, function (Fc), functional modes (FM), risk priority number (RPN) and Description of failure.
b) A3LAMDA template (as shown in Figure 5-3) – to visualise and solve the design problem, also to capture the created knowledge and problem solver's understanding by using the ten elements provided and structured in the A3LAMDA template. In addition, as an effective communication tool to support design decision making.
c) Knowledge database – In the process of the A3 thinking approach, the knowledge database has two important functions; firstly, to capture and compile the knowledge created in the A3LAMDA reports throughout problem solving, hence creating useful knowledge to be shared and applied; secondly, it functions as a design reference compiled as Design Statement Checklist (DSC), as explained at the end of section 5.5. However, this is only a proposed idea resulting from the research work. The knowledge database will be a design reference for designers in two situations as follows:

- Problem prevention: To facilitate designers in the avoidance of design problems which happened in product design by considering design recommendations before design testing.
- Problem solving: To facilitate designers in identifying and proposing the solutions to address the design problems. By identifying the root cause analysis and related design issues, the potential solutions could be defined easily and faster by searching the DSC.

Each of the key roles involved in the process of the A3 thinking approach is described in Table 5-8 which explains the key roles and their descriptions.

Key Roles	Descriptions
Top Management	The highest ranking executives (chief executive officer, managing director, vice president) who are entirely responsible for the success and failure of the organisational company.
Human Resource Management	Functions within the organisational company that focuses on managing the employees and ensuring they are contributing effectively and productively to the overall company direction.
Employees	A particular group of people hired to provide services to an organisational company.
A3 Thinking Expert	An A3 expert who will facilitate and train the A3LAMDA owner in the company to implement the A3 thinking approach to solve problems in product design.
Problem identifier	The person who first identified and found the problem.
A3LAMDA owner	The person who is skilled and has been properly trained to solve design problems using the A3 thinking approach.
Problem solving experts	The person, or group of people, who is/are expert(s) in particular design problems (internal or external)
A3 team	A group of people who have been selected by the A3LAMDA owner to be involved in design problem solving by using an A3 thinking approach (e.g.: problem identifier, A3LAMDA owner, problem solving experts)

Table 5-8: The Key Roles Descriptions

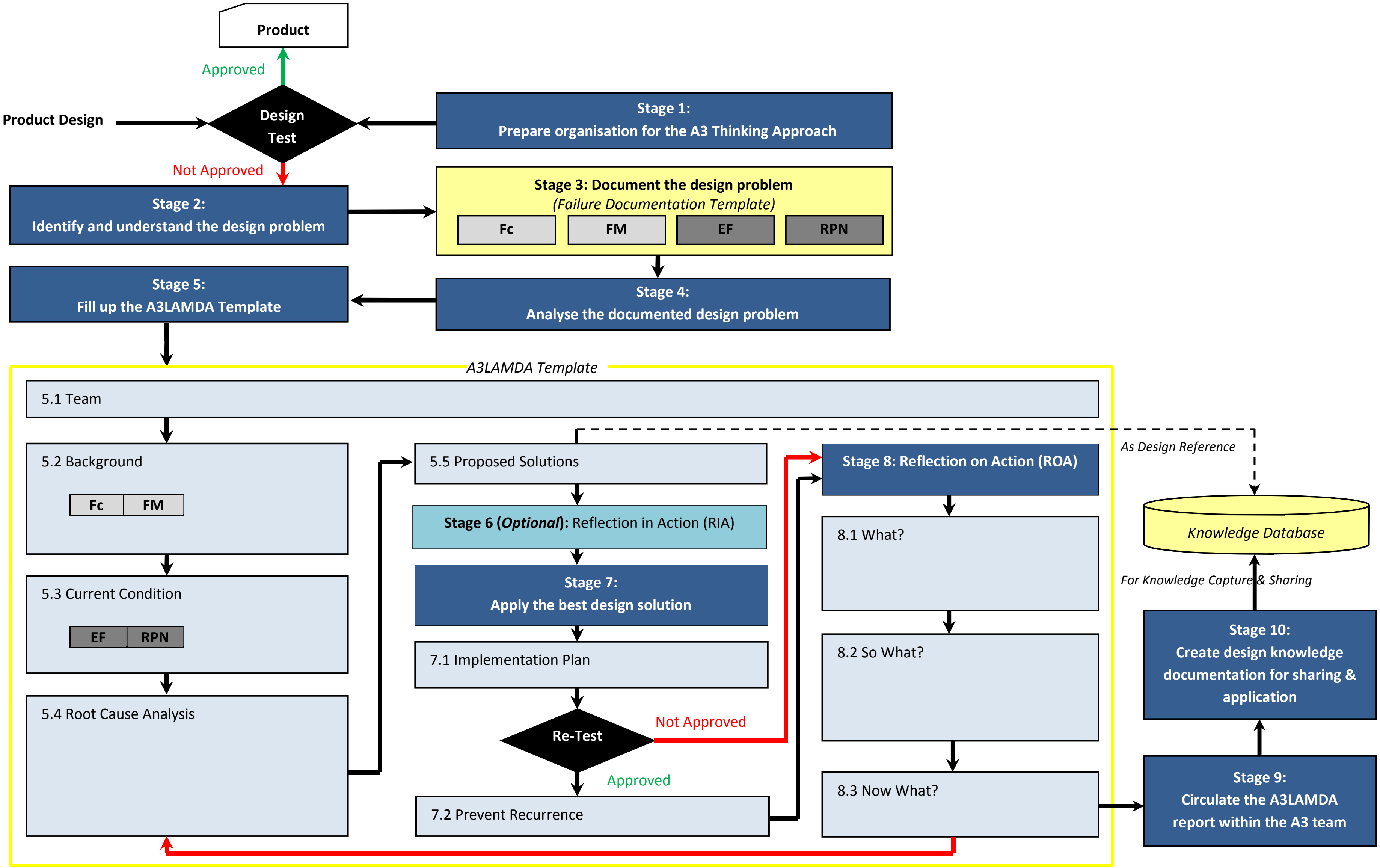


Figure 5-5: Process Flow of the A3 Thinking Approach

The following describes in detail the ten stages in the process of using the A3 thinking approach as shown in Figure 5-5. The descriptions of each stage are clarified based on four headings: key role, objective, process and output. The objective refers to the goal for each stage, whilst the process is the related activities in order to accomplish the objective. The output refers to the deliverable for each stage.

Stage 1: Prepare Organisation for the A3 Thinking Approach

Key Role: Top management, human resource management, A3 thinking expert and employees.

Objective: To build awareness of the A3 thinking approach within the employees by providing proper materials and training in order to develop and improve the skills in employing that approach, thereby enabling employees to undergo the process of design problem solving effectively.

Process: a) The management supports the A3 thinking initiatives.

b) Identify the A3 thinking expert (internal or external) to perform and deliver the training. Training sessions as follows:

- Deliver the training materials (slides presentation, reports)
- The A3LAMDA owner teaches and guides the new trainers to become experts in A3 thinking.
- The A3LAMDA owner monitors the performance of the new trainers.

c) The company standardises the implementation of the A3 Thinking Approach.

Output: Well-trained and skilled employees, well-prepared organisation, A3LAMDA owner(s), training materials and A3 thinking approach standardisation.

Stage 2: Identify and understand the design problem

Key Role: Problem identifier

Objective: To make people aware of the imperfections, symptoms or unexpected results that negatively affect the product design. Identifying and understanding the problem quickly leads the company towards improving the design process.

Process: a) Ensure that the design test has been conducted according to proper and recommended procedures.

b) Identify the solution that could be achieved through direct observation or via indicators and measurements.

c) Identify the important and necessary information and data to be documented.

Output: Details are relevant and important information/data and in-depth understanding of the identified design problem.

Stage 3: Document the design problem

Key Role: Problem identifier

Objective: To document and present the important details of a design problem.

Process: a) Fill in the "Failure Documentation" template as shown in Table 5-7.

b) Prioritise the problem by identifying if any similar problems happened in the past. This can be performed by referring to previous failure documentation template in the RPN section.

c) The problem identifier will document the design problem using the proposed Failure Documentation template explained in sub-section 5.6 and shown in Table 5-7. Most of the data can be gathered from the design process or client specifications reports.

d) The Failure Documentation report will be passed to the A3LAMDA owner and the problem solved using the A3 thinking approach.

Output: Documentation and presentation of the details design problem as a Failure Documentation report.

Stage 4: Analyse the documented design problem

Key Role: A3LAMDA owner

Objective: To analyse and understand the design problem effectively.

Process: a) Check and obtain confirmation from the test engineer that the design test has been done properly.

b) Review and analyse all the reports and procedures where their details are provided in the Failure Documentation report.

Output: The confirmation of the documented design problem.

<u>Stage 5: Fill up the A3LAMDA template</u>

Key Role: A3LAMDA owner

Objective: To undergo a process to solve the design problem by using the A3LAMDA template.

Process: Fill up an A3LAMDA template on which, at this stage, only elements 1-5 (Team until Proposed Solutions) are involved for solving the design problem.

Output: A3LAMDA report.

5.1 Team

Key Role: A3LAMDA owner

Objective: To build a core team that involves a responsible process owner, analysis, correction, and prevention of the problem.

Process: a) Identify and establish the people for the A3 team who are:

- Involved and responsible in the related process and/or in solving the design problems (e.g.: internal/external experts and problem identifier).
- Neither experts nor involved experts in the design problem. This is to encourage them during the discussion by asking 'why' (Arnott, 2004).

b) Inform on and discuss the problem to be solved.

c) Write the first element in the A3LAMDA template –Team.

Output: A3 Team

5.2 Background

Key Roles: A3 Team

Objective: To document the data captured in the Failure Documentation report (Function and Failure Mode).

Process: a) Understand and review the data needed and significance as the background element.

b) Write and provide any necessary and relevant information that the reader of the A3LAMDA report needs to know.

c) Choose the appropriate product picture for visualisation purposes and insert into the picture box. Make the product picture as clear as possible.

d) Obtain assistance from engineers or people involved in related areas to elicit more data.

Output: Background of the design problem is completed.

5.3 Current Condition

Key Role: A3 Team

Objective: To document the data captured in the Failure Documentation report (Risk Priority Number) and provide a description of the design problem by visualising the data as simply as possible.

Process: a) Identify and illustrate the current condition of the identified design problem.

b) Describe the effect of the failure accurately and make the overall context of the current condition as clear as possible.

c) Gain and collect the necessary and additional data using direct observation.

c) Insert the picture and data of the design test results. (e.g.: histogram, graph, emails, Pareto). Make the pictorial representation as clear and effective as possible.

Output: Current Condition description

5.4 Root Cause Analysis

Key Role: A3 Team

Objective: To investigate and define the possible root causes of the identified design problem.

Process: a) Discuss the defect and brainstorm the possible causes.

b) Identify and undergo the necessary diagnoses of the causes that might need to be performed in order to investigate the symptoms of the problem. Hence select those most related to the cause of the problem.

c) Identify the most useful techniques to identify/explain the root cause for the design problem (e.g.: Ask 'why' five times, fishbone diagram, tree diagram, and causal chains).

f) Present the causes and reasons for the design problem.

Output: Identification of root cause of the design problem.

5.5 Proposed Solutions

Key Role: A3 team

Objective: To explore a set of effective potential solutions in order to address the root cause of the design problem.

Process: a) Generate and model the potential solutions by brainstorming the following sources of knowledge to address the root cause of the problem:

i. **Tacit knowledge** (personal knowledge extracted from the individual concerned)

ii. **Knowledge database** (knowledge that has been documented and shared (As presented and explained in Figure 5-5).

b) List all the proposed solutions.

c) Undergo all the proposed solutions and observe the findings.

d) Compare the effectiveness of proposed solutions and potential disruptions as shown in Table 5-9. This table was developed by the author in cooperation with the collaborative company's stakeholders.

Confirmation			Types of Solution	
Not Effective	**Somehow Effective**	**Very Effective**	**Containment**	**Permanent**
- Solution will not solve the problem	- Solution has an effect on solving the problem but does not directly address the root cause of the problem.	- Solution that solves the problem effectively and directly addresses the root cause of the problem.	- Temporary solution to stop the fault within 24 hours immediately until a permanent corrective action can be implemented. - Not directly eliminating the root cause of the problem.	- Long-term solution that addresses and directly eliminates the root cause of the problem.

Table 5-9: Scales Confirmation and Type of Solutions

e) If the solutions need to change the design/model, insert a picture in the Design before Modification and the Design Reference in the A3LAMDA template. (e.g.: Print screen technique)

Output: Potential and verified design solutions.

<u>Stage 6: Reflection in Action (RIA) - Optional</u>

Key Role: A3 Team

Objectives: To reflect and verbalise an understanding that emerged while performing the root cause analysis and identify the solutions to solve the design problem and turn it into proper learning.

Process: a) Capture and document the lessons learned during the following discussion of:

i. Generating the possible causes and identifying the root cause of the design problem.

ii. Proposing the potential solutions and selecting the best design solution.

b) Start filling the reflection section which consists of the last three from ten elements in the A3LAMDA template:

i. What? (Eighth element) – What knowledge /lessons have you learned during problem solving? It is highly recommended that this be captured.

ii. So What? (Ninth element) – How can the knowledge be applied? Formulate the lessons learned captured in the eighth element (What?) into a design rule or design recommendation.

iii. Now What? (Tenth element) – Where is the knowledge needed? Identify where the knowledge is needed, which is captured in ninth element (So What?) according to the product development process chart (functions and activity).

Output: Lessons learned/Design Rule(s)/ Design Recommendation(s)

<u>Stage 7: Apply the suitable design solution</u>

Key Role: A3 Team

Objectives: To verify the selected solution in order to create new knowledge that needs to be captured and communicated for future design project reference.

Process: a) Based on Table 5-9, choose the suitable design solution as follows:

- First choice: Very Effective and Permanent **OR** Containment
- Second choice: Somehow Effective and Permanent **OR** Containment.

b) If the solutions need to redesign, insert a picture in the design before and after modification in the A3LAMDA template. (e.g.: Print screen technique)

c) Apply the best design solution.

d) Fill up the sixth and seventh elements (Implementation plan and prevent recurrence) in the A3LAMDA template to apply the best design solution.

Output: Verified design solution.

7.1 Implementation Plan

Key Role: A3 Team

Objective: To provide the future action(s) that must be performed to realise the best design solutions and verify and control the effectiveness.

Process: a) Identify the corrective actions by highlighting the main tasks, actions, person responsible, and deadline.

b) Document the implementation plan using a Gantt chart.

c) Follow and implement the plan and observe new results (fail or pass).

d) The design test results contain two possible outputs; pass and fail. The design that fails the test should return to root cause analysis whereas the pass result moves to the next stages.

Output: Detailed implementation plan.

7.2 Prevent Recurrence

Key Roles: A3 Team

Objectives: To prevent problem recurrence by i) modifying and controlling the performance to prevent the same problem, ii) standardising and deployment of corrective actions or process improvements, and iii) reflecting on the design changes and sustaining continuous improvement.

Process: a) Look at similar processes that can benefit from the countermeasure.

b) Modify and control the performance to prevent the same design problem.

Output: Impact and consequences of the verified solutions to sustain continuous improvements and prevent recurrence in the future.

Stage 8: Reflection on Action (ROA)

Key Role: A3 Team

Objective: To capture a tacit understanding and knowledge created from verified solution and turn it into proper learning.

Process: a) Capture the lesson learned from the created knowledge.

b) Start filling in the reflection section in the A3LAMDA template (What, So what and Now what)

Output: The created knowledge is captured.

8.1 The reflection – What is the knowledge?

Key Role: A3 Team

Objective: To reflect and capture the created knowledge or experience after the problem solving activities.

Process: Capture and list all the lessons learned.

Output: List of lessons learned.

8.2 The reflection – So What? (How can the knowledge be applied?)

Key Role: A3 Team

Objective: To standardise and represent the knowledge or lessons learned as a design rule or design recommendation so it can be applied and shared in future projects.

Process: a) Select and identify the lessons learned which are most important and give greater impacts to the people, process and company.

b) Formulate the lessons learned into standard knowledge (Design rule or Design recommendation) to be applied in the future.

c) Identify which types of design problem relate to the useful knowledge.

Output: Design rule or Design recommendation for specific design issues.

8.3 The reflection – Now What? (Where is the knowledge needed?)

Key Role: A3 Team

Objective: To circulate and share the useful knowledge in order to ensure it will be applied by the right people at the right time.

Process: a) Identify trigger points.

b) Be familiar with the process, functions or activities in product development.

Output: Knowledge standardisation.

Stage 9: Circulate the A3LAMDA report within the A3 team

Key Role: A3LAMDA owner

Objective: To verify and finalise the A3LAMDA report, especially at the reflection section within the A3 team.

Process: a) Circulate the A3LAMDA report (emails, meetings, hardcopy, and softcopy).

b) Keep updating the A3LAMDA report if there is additional feedback and opinions from the A3 team in the reflection section.

Output: The verification of the A3LAMDA report within the A3 team.

Stage 10: Create design knowledge documentation for sharing and application

Key Role: Top Management, employees, human resources management and A3LAMDA owner

Objective: To ensure the provision of the useful knowledge can be shared and communicated effectively to enrich knowledge environment, hence to support decision making for future design projects.

Process: a) Identify the environment to enrich the knowledge environment via the A3LAMDA report (hardcopy e.g.: cafe/meeting room/test room).

b) Capture and compile the design rule and design recommendations in a knowledge database.

c) Transfer the useful knowledge into a design statement checklist (DSC) and distribute and inform those who have been identified as needing the knowledge.

d) Verify the knowledge by expert people.

e) Top management is to ensure that the design reference or design statement checklist is successfully shared and applied.

Output: Design Statement Checklist (DSC) as design reference.

The detailed process of the A3 thinking approach, which was developed with ten stages, has been explained from knowledge creation and capture, hence useful knowledge is created for design reference and to facilitate decision making in product design. The next section presents an alternative by adopting the A3LAMDA template that was developed by the author in Microsoft Word Developer. It can be used as a conceptual idea for the design implementation of a software system in future.

5.8 A3LAMDA Template in Microsoft Word Developer

This section presents the development of the A3LAMDA template using Microsoft Word (Developer) 2007. Currently, implementation of the traditional A3 template is paper-based. However, the implementation of the A3LAMDA template as softcopy could be beneficial. Therefore, this research has developed the A3LAMDA template (See Appendix 11 for the A3LAMDA template interface), designed in Microsoft Word developer, which aims to speed-up the process of documenting or filling in the A3LAMDA template. This A3LAMDA template was developed on A3 standard size paper (29.7cm x42cm) and consists of 10 boxes representing the 10 elements. Each of the elements includes some appropriate forms buttons as represented in Table 5-10, namely: Date picker, Rich text, Picture content control, Check box and Drop-down list.

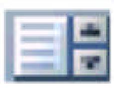
Form Buttons	Descriptions	Elements	Steps
Date Picker 	Contains a calendar control.	- Team (Date)	Left click then choose the date.
Rich Text 	A rich text control can contain custom formatted text or other items, such as tables, pictures, or other content controls.	- All elements	Left click and text.
Picture Content Control 	This button has two functions for this model: a. To fill the content control with a single image. This is directly imported from the picture database.	- Background - Current condition - Implementation Plan	Left click then the picture database will appear. Select the required picture for visualisation.
	b. As hyperlinks to the Failure Documentation Reports, Previous A3LAMDA reports, Product Development Process Chart (to identify where the knowledge is needed at the functions/activity in the product development process)	- Proposed solutions - Background - Reflection (Now What)	Right click, click Open Hyperlink then the file will appear. This file can only be saved as a PDF or image.
Check Box 	A check box provides a GUI (Graphical User Interface) that represents a binary state.	- Root cause analysis - Proposed Solutions - Prevent recurrence - Reflection (What and Now what) sections	Tick to the boxes.
Drop-down List 	A drop-down list displays a drop-down list of entries that users can select.	- Background - Current condition - Reflection (So what & Now What) Sections	Click and drop-down to select the appropriate ones.

Table 5-10: Word Developer Form Buttons used for the A3LAMDA Template

Before starting the application of the A3LAMDA template in Word Developer, the following steps are needed in order to display the Developer tab on the screen computer:

1. Start the Microsoft Word Office application.
2. Click the Microsoft Office button, and then choose Word Options.
3. In the categories pane, choose Popular.
4. Select the Show Developer tab in the Ribbon check box.

5. Choose the OK button to close the Options dialog box.
6. The Developer tab will be displayed after the View tab.

Once the developer tab is displayed on the ribbon, then the model of A3LAMDA template is ready to be used. Below are the steps to use the model of the A3LAMDA template in Microsoft Office Word 2007 Developer using Windows 7.

7. Click the Developer tab.
8. In the Protect section of the Developer tab, click Restrict Editing. Then the Restrict Formatting and Editing task will appear at the right hand side.
9. Click Yes, Start Enforcing Protection in the Start Enforcement.
10. The Protection Method appears on the screen. This is optional. If desired, enter a password (any) to protect the document from being changed by others. However, the password cannot be retrieved.
11. Click Stop Protection if the template is completed. The Protection Method appears again, and then enters the same password in step 10.

The knowledge database compiled from the A3LAMDA reports provides an alternative way of future problem solving in product design. This will help designers or problem solvers to understand the origin of useful knowledge by capturing the overall problem solving activities before and after reached design solutions in the A3LAMDA reports. In order to speed up the process in accessing the files, the hyperlinks tool as explained in Table 5-10, represents as a picture icon, has been used and structured into the A3LAMDA template. This means that any files can be accessed from the front view model. The author has identified three important files needed during solving the design problem: Failure Documentation report, Previous A3LAMDA reports and Product Development Process Chart. These are explained as follows:

a) Failure Documentation Reports: structured at the top of the second element (Background) in the A3LAMDA template aims to help the designer review and analyse the data from the documented design problem in the Failure Documentation report as shown in Figure 5-6.

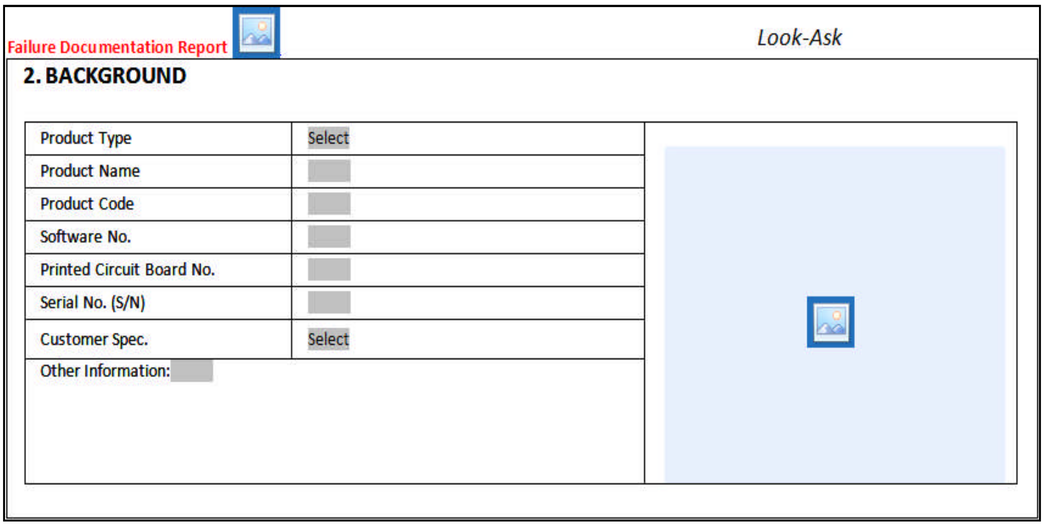


Figure 5-6: Icon of Failure Documentation Reports in the A3LAMDA Template

b) **Previous A3LAMDA Reports:** structured at the proposed solutions element in the A3LAMDA template as shown in Figure 5-7. It aims to help the designer to capture the knowledge from previous documentation of A3LAMDA reports once the root cause of the problem has been identified. Documenting the A3LAMDA report by following the type of design issues is highly recommended. This will help the designers to access the A3LAMDA reports that are only related to the identified problem, hence the root cause of the problem can be addressed. This will encourage and enforce the future product designers or engineers to digest the whole A3LAMDA report as the documented information and knowledge captured. In addition, it will enable the designers to understand the linkage between hypothesis and practice which results in new learning and understanding before solving the problem. This is one of the appropriate techniques for tacit knowledge sharing and transfer by understanding the whole situation from previous documented A3LAMDA reports.

5. PROPOSED SOLUTIONS Previous A3LAMDA Reports

No.	Proposed Solutions	Effectiveness			Types Solution	
		Not	S/how	Very	Cont	Perm
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐

Figure 5-7: Icon of Previous A3LAMDA Reports in the A3LAMDA Template

c) **Product Development Process Chart:** structured at the final element (Now What) in the A3LAMDA template as shown in Figure 5-8. The idea is to assist the A3LAMDA owner to identify where the knowledge is needed easily and efficiently from the chart. This could be of benefit to new designers who are not familiar with the product development process structures.

10. Now What? *Where the knowledge is needed?* Product Development Process Chart

DR/Rec	Function	Activity
Select	Select	Select
Select	Select	Select
Select	Select	Select
Select	Select	Select
Select	Select	Select

Figure 5-8: Icon of Product Development Process Chart in the A3LAMDA Template

Any files could also be structured according to this model, for example the A3LAMDA guideline. This could facilitate the A3LAMDA owner to refresh their skills before proceeding to solve the problem. The advantage of using this model is that no one can edit any data in the A3LAMDA report except the A3LAMDA owner, as the first step before filling in the template is to generate and key in the password. In addition, the

A3LAMDA owner can add–up any files that need to be considered whilst filling in the template. The disadvantage is that some of the rows which are using the rich text button have been developed with a limit on the total number of words.

For future development, the A3LAMDA template could be designed as a one application, for example for an IPad, a table computer designed by Apple Inc. or Samsung Galaxy Note developed by Samsung Manufacturer (http://en.wikipedia.org/wiki/IPad) and supported with a stylus pen which is simply replacing the use of a finger. This technology will be an effective approach for the designer where the picture and data can be snapped and installed at the same time, hence enhancing communication within a design team to solve problem in product design.

5.9 Chapter Summary

The identified limitations have shown that the current problem solving approaches do not fulfil the capabilities of knowledge management. In order to address this issue, Section 5.2 has presented the development of the A3 thinking approach to support knowledge driven design and the definition has been clearly explained. In Sections 5.3, 5.4 and 5.5, the author described in detail two sections in the A3LAMDA template. The first section for knowledge creation was provided with seven elements whereas the second section focused on reflection for knowledge capture. Section 5.6 presented the failure documentation template to ensure that the identified design problem will be properly documented. In Section 5.7, the process of using the A3 thinking approach containing ten stages was explained. Section 5.8 presented the development of the A3LAMDA template in Microsoft word developer. This is an alternative for the designers in product design for utilising the A3 thinking approach. In the following chapter, the A3 thinking approach explains the validation methods in order to define the effectiveness of knowledge creation, capture and sharing. Meanwhile, the validation sessions within the collaborative company will be presented in order to verify and validate the credibility of the research study.

Chapter 6

6 CASE STUDIES FOR VALIDATION

6.1 Introduction

In Chapter 5, the author presented and explained the development of a novel A3 thinking approach, the A3LAMDA template and the process required to use it. Two methods which have been used to validate the proposed approach are: industrial case studies and expert judgements and these are presented in this chapter. The former is selected and performed as a requirement from LeanPPD business partners whilst the latter is to reduce bias as this research is a qualitative study. The author defined the 'expert' in expert judgements as a person who is fully and directly associated with this research or has experience of more than five years in problem solving and product development.

The remaining sections are as follows: Section 6.2 presents the first validation method which is the industrial case studies that were performed with a company. Section 6.3 presents the industrial experts' judgements that have been captured from the experts who have been fully and directly associated with the research. The judgements based on the proposed approach during the LeanPPD industrial workshops have been captured and this is explained in Section 6.4. Finally, the chapter is summarised in Section 6.5.

6.2 Industrial Case Studies

Four industrial case studies have been employed to validate and verify the A3 thinking approach in the collaborative company and this has generated six A3LAMDA reports. For confidentiality reasons, the A3LAMDA reports presented in this chapter have been modified to protect the sensitive data, including the design layouts or product pictures. These case studies have been performed using different electromagnetic compatibility (EMC) roles and background. The following explains the aims of each of the case studies:

1. **Case study 1: Documenting solved design problem** – This case study was aimed at helping the designers to become familiar with and properly employ the A3LAMDA template, hence to capture and document if there are any lessons learned from a solved design problem; in addition, it was to convince the designers that the A3LAMDA template is easy to understand, and simple to follow and apply to design solution documentation.
2. **Case study 2: Solving actual design problem** – This case study was aimed at visualising important data and to solve a real EMC design problem. Hence it would capture and formulate the created knowledge from the problem solving activities to be documented in the A3LAMDA template utilising the process of the new A3 thinking approach proposed in Section 5.7.
3. **Case study 3: Partial solution and documentation** – This case study was aimed at evaluating the use of the A3LAMDA template and to ascertain the starting point of knowledge capture, even though all its elements have not been completed.
4. **Case study 4: Generating & re-use of knowledge** – This case study was aimed at collecting all the knowledge created and captured during and after solving the EMC design problem, which was then documented in the A3LAMDA reports throughout the case studies. Hence it would provide and distribute useful knowledge within the organisational company to be shared and then applied to future design projects.

The following sub-section presents in more detail each of the case studies.

6.2.1 Case study 1: Documenting Solved Design Problem

This case study was undertaken with an EMC designer (expert 1) who has more than 10 years' experience related to EMC. The EMC design problem is related to an Audio-Lx product which failed the conducted immunity (CI) test. The root cause of this problem was identified as the circuit design. Expert 1 and two EMC engineers solved the problem by selecting operation modes in the layout test plan. This design problem and the associated solution were documented in different EMC documentation files. This makes them difficult to re-use and hence increased the complexity of retrieving the important data and knowledge. Therefore, the aim was to re-document this solved design problem using the A3LAMDA template to generate a single document called the A3LAMDA report. The author prepared and provided the A3LAMDA template as shown in Figure 5-3 in both softcopy (Microsoft word developer) and hardcopy which gave the alternatives to expert 1 in order to complete the A3LAMDA template. At the same time it was an opportunity for the author to 1) familiarise the designers and engineers with the A3LAMDA template, 2) demonstrate that the A3LAMDA template is easy to use and follow, and 3) gather feedback in order to enhance the design of the template.

The data transfer of the EMC documentation files into a single A3LAMDA template is illustrated in Figure 6-1. These three document files are related to the 'Lx+ DAB Vxyx' audio that failed the CI test. The A3LAMDA report for this case study is shown in Figure 6-2. The EMC test report provides an explanation of the product, equipment and test details. The problem solving report and 8 Disciplines (8D) are the methods used to document the important information of solved or unsolved EMC problems. The problem solving report is the informal documentation which is recorded individually, whilst the 8D log file is the documentation of the EMC problem solving based on the 8D approach. These different documents increase the complexity of capture and re-use of the knowledge. Figure 6-1 illustrates how expert 1 documented the 'Lx+ DAB Vxyx' audio problem into the A3LAMDA template. The blue box represents the element (‘background’) which gives the data obtained from the EMC test report, such as product type, name and code, software number, PCB and serial numbers, and customer specification. The green boxes represent the three elements (‘current condition’, ‘root cause analysis’ and ‘proposed solutions’) in the A3LAMDA report which are the data obtained from the problem solving report. Finally, the red box represents the elements of ‘implementation plan’ and ‘follow-up and prevent recurrence’ which are the data obtained from the 8D log file. The reflection section proposed in this thesis was documented by expert 1 based on his lessons learned while solving the ‘Lx+ DAB Vxyx’ audio problem. One lesson learned has been captured which has guided expert 1 to generate design recommendations for the EMC test plan review, as shown in the reflection section in Figure 6-2. The completed A3LAMDA report, as in Figure 6-2, shows that the aim of case study 1 was accomplished. The following explains in detail the second case study, namely solving an actual EMC design problem.

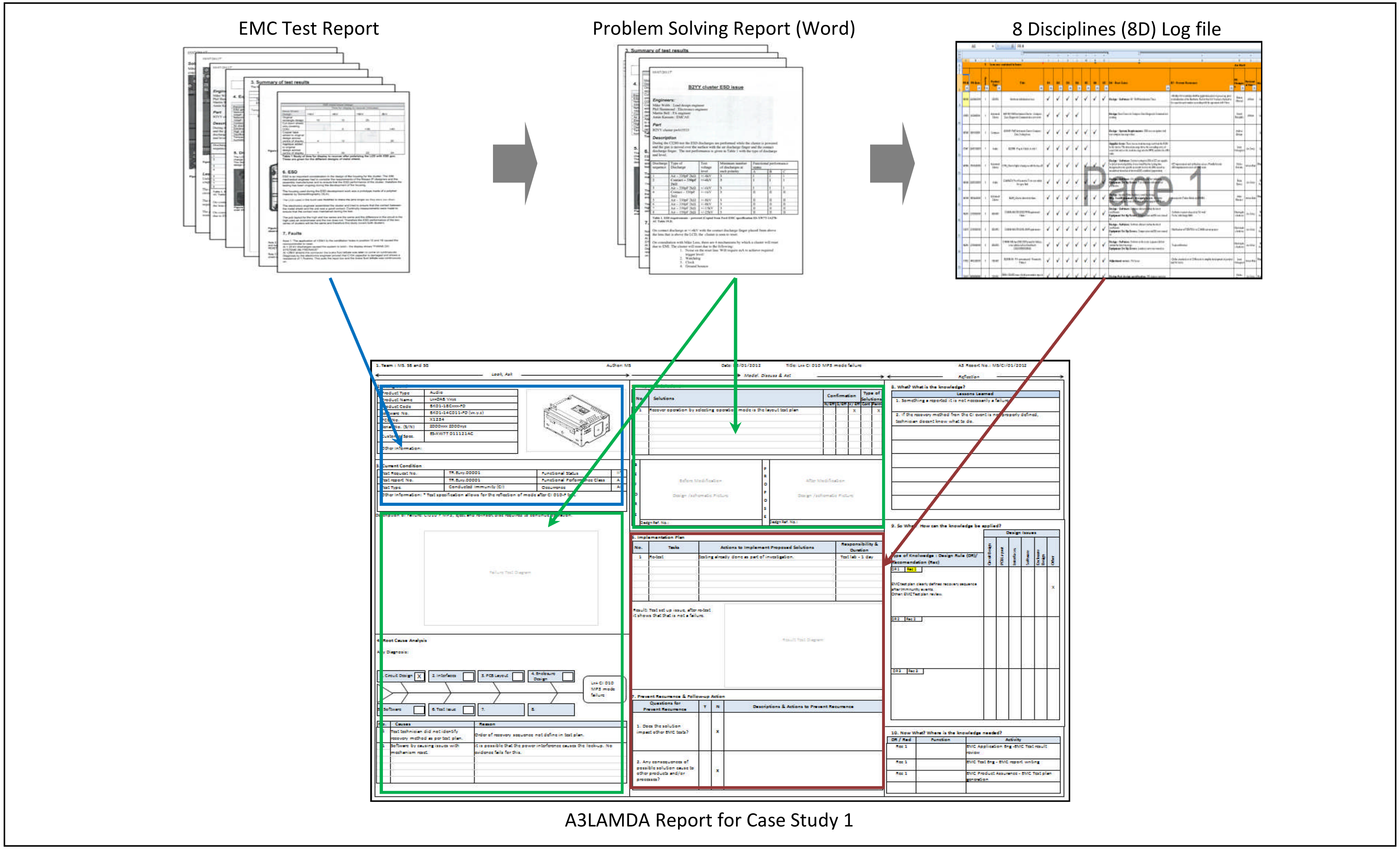


Figure 6-1: Data Transfer of EMC Documentation Files into a Single A3LAMDA Template

Figure 6-2: A3LAMDA Report for Case Study 1

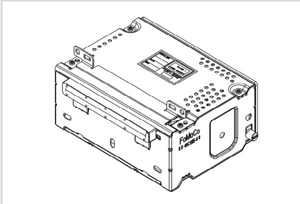
(Please Refer Figure 6-2 at the Folder of 'Figures and Appendices')

1. Team : MS, SB and SG   Author: MS   Date: 03/01/2012   Title: Lx+ CI 010 MP3 mode failure   A3 Report No.: MS/CI/01/2012

Look, Ask → *Model, Discuss & Act* → *Reflection*

2. Background

Product Type	Audio
Product Name	Lx+DAB Vxyz
Product Code	BK01-18Cxxx-FD
Software No.	BK01-14C011-FD (vx.y.z)
PCB No.	X1234
Serial No. (S/N)	Z000xxx Z000xyz
Customer Spec.	ES-XW7T 011121AC
Other Information:	



3. Current Condition

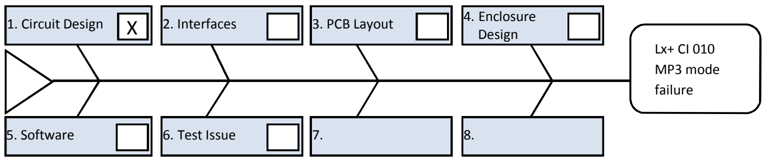
Test Request No.	TR.ELxy.00001	Functional Status	II*
Test report No.	TR.ELxy.00001	Functional Performance Class	A
Test Type.	Conducted Immunity (CI)	Occurrence	All
Other Information: * Test specification allows for the reflection of mode after CI 010-F test.			

Description of Failure: CI010 F MP3, Eject and re-insert disc required to continue operation.

Failure Test Diagram

4. Root Cause Analysis

Any Diagnosis:



No.	Causes	Reason
1.1	Test technician did not identify recovery method as per test plan.	Order of recovery sequence not define in test plan.
1.2	Software by causing issues with mechanism reset.	it is possible that the power interference causes the lock-up. No evidence fails for this.

5. Proposed Solutions

No	Solutions	Confirmation N/Eff	Confirmation S/Eff	Confirmation V/ Eff	Type of Solutions Cont	Type of Solutions Perm
1.1	Recover operation by selecting operation mode is the layout test plan			X		X

BEFORE		AFTER	
	Before Modification Design /schematic Picture		After Modification Design /schematic Picture
	Design Ref. No.:		Design Ref. No.:

6. Implementation Plan

No.	Tasks	Actions to Implement Proposed Solutions	Responsibility & Duration
1	Re-test	testing already done as part of investigation.	Test lab - 1 day

Result: Test set up issue, after re-test it shows that that is not a failure.

Result Test Diagram

7. Prevent Recurrence & Follow-up Action

Questions for Prevent Recurrence	Y	N	Descriptions & Actions to Prevent Recurrence
1. Does the solution impact other EMC tests?		X	
2. Any consequences of possible solution cause to other products and/or processes?		X	

8. What? What is the knowledge?

Lessons Learned
1. If the recovery method fron the CI event is not properly defined, technician doesnt know what to do.

9. So What? How can the knowledge be applied?

Type of Knolwedge : Design Rule (DR)/ Recomendation (Rec)	Design Issues: Circuit Design	PCB Layout	Interfaces	Software	Enclosure Design	Other
DR 1 / Rec 1 EMC test plan clearly defines recovery sequence after immnunity events. Other: EMC Test plan review.						X
DR 2 / Rec 2						
DR 3 / Rec 3						

10. Now What? Where is the knowledge needed?

DR / Red	Function	Activity
Rec 1		EMC Application Eng -EMC Test result review
Rec 1		EMC Test Eng - EMC report writing
Rec 1		EMC Product Assurance - EMC Test plan generation

Figure 6-2: A3LAMDA Report for Case Study 1

6.2.2 Case study 2: Solving Actual Design Problem

The EMC development process in collaborative company has been developed as shown in Figure 6-3, as a common understanding in order to address the EMC design problems. This figure explains the case of a product failing the test means, there is a design problem that must be solved by the designer. Thus, the design is modified and new prototypes are made, followed by re-testing. The recurrence of the EMC design problems is not going to be improved unless capturing and re-using the knowledge is created as a result of solving the problem.

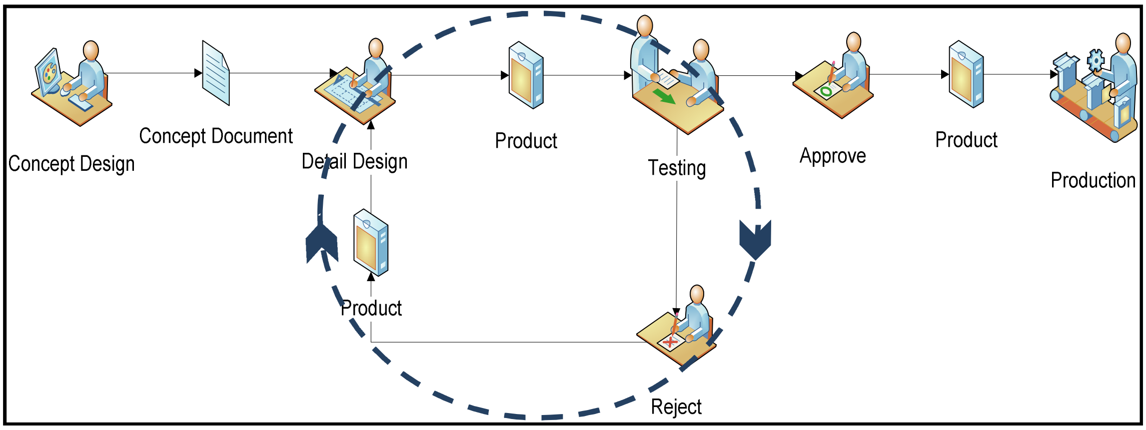


Figure 6-3: As-Is Workflow Diagram of the Product Development Process in the Collaborative Company (Mohd Saad et al., 2013; Maksimovic, 2013)

This second case study was performed by solving actual EMC design problems that happened and were followed according to the process of using the A3 thinking approach which contains ten stages, as explained in Section 5.7. Figure 6-4 shows the proposed To-Be workflow of an improved product workflow diagram which contains six key activities highlighted as follows:

1. Start concept design then detail design
2. EMC physical prototype testing; Test passes and fails
3. Document the design problem
4. Problem solving using the A3 thinking approach
5. Modify the design using the proposed solution from A3
6. Re-test (If it has failed, then repeat from activity 3)

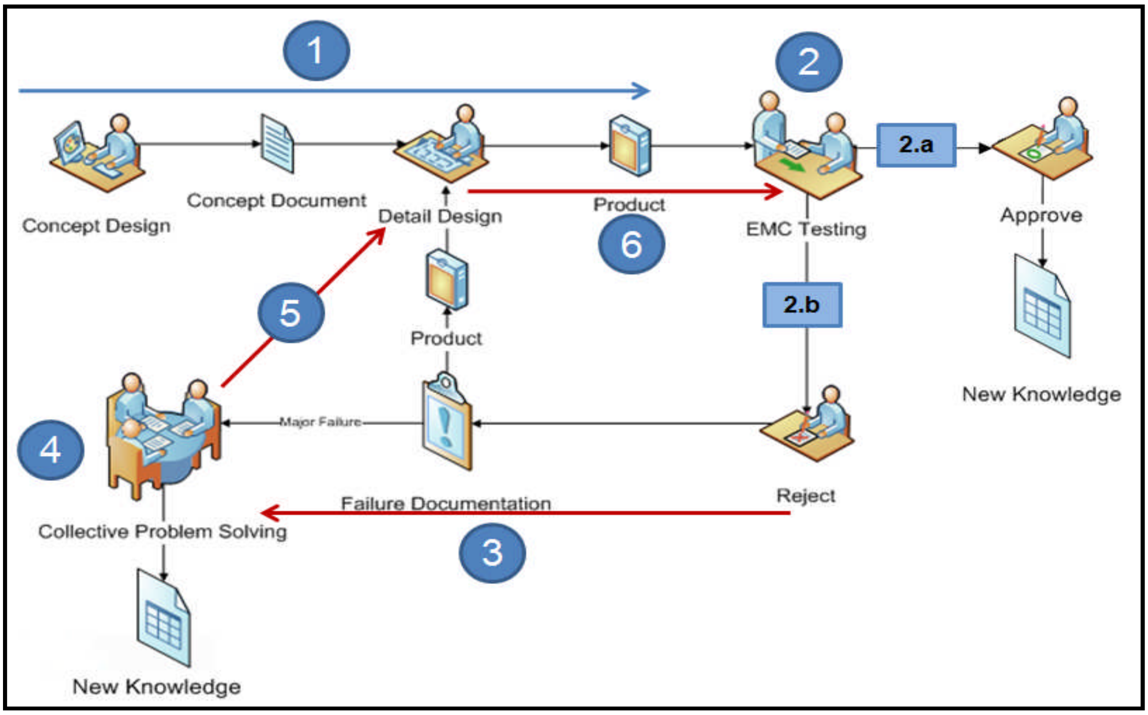


Figure 6-4: Stages of the To-Be Workflow Diagram for the Collaborative Company (Mohd Saad et al., 2013;Maksimovic, 2013)

The second case study focuses on activity numbers three and four which is to document and solve the actual EMC design problem by using the A3 thinking approach. Table 6-1 presents the titles and job roles at the collaborative company involved in the design audio problem solving that failed the radiated immunity test. The author of this thesis was involved for several days with this A3 team in the collaborative company. The radiated immunity test is to determine the ability of the electronic product to function in high power transmitters such as amplitude modulation and frequency modulation. The radiated immunity test which has been performed by the EMC test engineer starts with illuminate the x-audio with typical waveforms and signal strengths to simulate the worst case that the x-audio could encounter. From the ten stages proposed for the process of using the A3 thinking approach explained in Section 5.7, the first stage is not explained in the validation chapter as the author has organised the A3 thinking approach in the collaborative company.

Titles	Job Roles	Descriptions
Top Management	• Collaborative company Human Division	The highest ranking executives; those are entirely responsible for the success and failure for the collaborative company.
Problem identifier	• EMC Test Engineer	Person who performed the EMC test and identified the problem.
A3LAMDA owner	• EMC Designer	Person who has skill and has been trained by A3 thinking expert to solve the EMC design problem.
Problem solving experts	• EMC Application Engineer • Lead Engineer • Radio Frequency & Antenna Specialist • Radio Electrical Engineer	The group of people who are experts in relation to the EMC design problems and process.
A3 Team	• All above except Top Management	A group of people who have been selected by the A3LAMDA owner to be involved in design problem solving activities by using the A3 thinking approach.

Table 6-1: The Job Roles for Case Study 2

Stage 2: Identify and understand the design problem

The EMC Test Engineer has performed the radiated immunity test or RI114 for X-Audio. THE ‘114’ is based on the client’s specification number of the Absorber Lined Shielded Enclosure (ALSE) method. However, the test has failed where the results shows that the X-Audio drops out but recovers with 2 seconds dwell at 580-610MHz and 720-760MHz. When a longer dwell time is used due to a thresholding (image segmentation) routine, the device under test (DUT) does not self-recover. The client’s requirement is for a minimum dwell time of 2 seconds, longer dwell times may be necessary if the device under test function response times are expected to be longer.

Stage 3: Document the design problem

The EMC test engineer proceeds to document the RI114 failure and capture the important and necessary data. The author has proposed the use of a Failure Documentation template, as explained in Section 5.6 of Chapter 5. The Failure Documentation report is shown in Table 6-2.

<table>
<tr><th colspan="6">Input of Failure Documentation</th></tr>
<tr><td colspan="6">a) Title: Lxy+ 123 DAB RI114 failure</td></tr>
<tr><td colspan="2">b) Function (Fc)</td><td colspan="2">c) Failure Mode (FM)</td><td colspan="2">d) Risk priority Number</td></tr>
<tr><td>Product Type</td><td>X-Audio</td><td>Test Type</td><td>RI114</td><td>Functional Status (For Immunity only)</td><td>II</td></tr>
<tr><td>Product Name</td><td>Vxxx Lxy+ radio</td><td>Customer Spec.</td><td>XYZ.01.0101</td><td>Functional Performance Class (For Immunity only)</td><td>A</td></tr>
<tr><td>Product Code</td><td>BKxx1-xxxxx-01</td><td>Test Request No.</td><td>TR.ELXX.XXXX</td><td>Occurrence</td><td>All</td></tr>
<tr><td>Software Number</td><td>BKxx1-xxC0xx-01 (v08.X.X)</td><td colspan="4" rowspan="3">Other Information ; No</td></tr>
<tr><td>Serial. No. (S/N)</td><td>Z000XYZ; Z000ZYX</td></tr>
<tr><td>Printed Circuit Board No.</td><td>XYX01</td></tr>
<tr><td colspan="6">d) Description of failure: The effect of failure has been identified which, only for interference, applied for more than 15 seconds.</td></tr>
</table>

Table 6-2: Failure Documentation Report for RI114 Failure

The EMC Test Engineer then notified the problem immediately by phone calls and emailed the results obtained showing the EMC problem. He sent an email of the Failure Documentation report to expert 1 (A3LAMDA owner) to solve the RI114 (Radiated Immunity) failure using the A3 thinking approach. The EMC test engineer recorded the Failure Documentation report by uploading the file in the system for follow-up status and future reference.

Stage 4: Analyse the documented design problem

The A3LAMDA owner has analysed and checked the failure documentation report as shown in Table 6-2 to ensure the RI114 test was performed by following the client's specification and the test failure was documented in a proper way. Also, the entire related test procedures were reviewed. A few questions also have been asked of the EMC test engineer via phone calls to confirm the problem, such as when and how the problem had been identified. As a result, the A3LAMDA owner confirmed that the RI114 Radiated Immunity was a major EMC design problem that needed to be solved immediately.

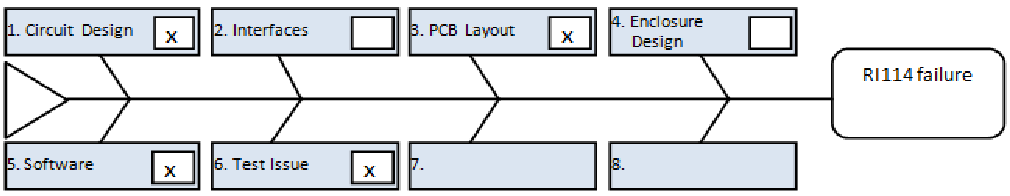
Stage 5: Fill-up the A3LAMDA template

The A3LAMDA owner (EMC Designer) then starts filling in the A3LAMDA template by sequentially following the elements and undergoing the process to solve the RI114 (Radiated Immunity) test failure. The following explains the elements as shown in A3LAMDA report for case study 2 (refer to Figure 6-10).

- **Element 1: Team** – The A3LAMDA owner identified and selected five EMC engineers (two application engineers, test engineer, software engineer and design engineer) who have been involved and have solved RI failures in the past. Those engineers have been informed through emails, phone calls and face-to-face discussions by the EMC Test Engineer. The A3LAMDA owner starts filling up the A3LAMDA template as shown in Figure 5-4 by documenting the six persons involved in A3 team; date started to solve the RI114 (Radiated Immunity) problem, title and A3 reference number (author/EMC design test/ month/ year).
- **Element 2: Background** – The A3LAMDA owner directly transferred the data captured in the Failure Documentation report and transferred them to the Background element. For visualisation and recognition purposes, the product picture has been captured and documented in this element.
- **Element 3: Current Condition** – The A3LAMDA owner directly transferred the data captured in the Failure Documentation report and transferred them to the Current Condition element. Since the test's result is not provided with any data or graphs, the A3LAMDA owner reads and understands the emails sent by the EMC Test Engineer who confirmed the problem and documented it in this element. Both these elements (Background and Current Condition) are the inter-relations between elements in Failure Documentation and A3LAMDA reports to ensure the speed and accuracy of the process to solve the problems.
- **Element 4: Root Cause Analysis** – This element was performed by members of an A3 team who were considered experts in RI114 (Radiated Immunity) for x-audio. The four identified potential causes in the A3LAMDA report are shown in Figure 6-5. This figure shows the results from the several diagnoses and has identified the related type of EMC design issues, which are 1) circuit design, 3)

PCB layout, 5) software and 6) test issue. The table (below the fishbone diagram) in Figure 6-5 presents the number of EMC design issues provided in the fishbone diagram, the cause of each EMC design issue and the reason. Some of the reasons were identified based on the 5 whys approach. For example, the first RI114 failure was a circuit design issue. This could be caused by serial peripheral interface (SPI) to digital audio broadcasting (DAB) module being vulnerable to interference. This is due to failure consistent with serial peripheral interface communication failure.

4. Root Cause Analysis



No.	Causes	Reason
1	SPI interface to DAB module vulnerable to interference.	Failure consistent with SPI communication failure. Issue not seen on DAB on Main Board variant with different filtering.
3	Layout issues on SPI lines	Layout is different to DAB on main board design.
5	Software does not handle SPI errors gracefully.	Return to FM mode is consistent with DAB source being deallocated.
6	Field being applied too long due to auto-thresholding.	If field is only applied for 2s, self recovery is seen.

Figure 6-5: Root Cause Analysis of the RI114 Failure

- **Element 5: Proposed Solutions** – The potential solutions were identified and generated as a group decision within the A3 team based on the root cause analysis shown in Figure 6-5. Figure 6-6 presents the proposed solutions for RI114 failure and these are explained as follows:
    - Circuit design issue: solve by changing the filtering on the 'Vxxx' product to be similar to that of the digital audio broadcasting (DAB) on the main board.
    - PCB layout issue: solve by reviewing and changing the layout if appropriate (no changes yet identified).

- Software issue: solve by modifying the software to stop communications to digital audio broadcasting (DAB) module while serial peripheral interface (SPI) errors seen (not tried).
- Test issue: solve by changing the test procedure to do non-audio test for level 2 so interference is not applied for as long as 15s.

No	Solutions	Confirmation			Type of Solutions	
		N/Eff	S/Eff	V/ Eff	Cont	Perm
1	Change filtering on Vxxx to be similar to that on DAB on main board.	X				
3	Review and change layout if appropriate.(Not changes yet identified)					
5	Modify software to stop communications to DAB module while SPI errors seen (not tried).					
6	Change test procedure to do non-audio test for level x so interference not applied for as long as 15s.			X	X	

BEFORE		PROPOSE	
	Unit drops to FM mode for 580-610MHz and 720-760MHz at Level 2. Typical thresholds at 80-90V/m		DAB Audio signal drops out but self recovers.
	Design Ref. No.:		Design Ref. No.:

Figure 6-6: Proposed Solutions of the RI114 Failure

Stage 6: Reflection in Action (RIA)

This stage is optional for designers however, until this point the A3LAMDA owner successfully captured two lessons learned while identifying the potential root causes and proposing the solutions within the A3 team as follows:

- Need to consider effect of longer periods of interference and specify in test plan if required.
- Need to pay special attention to immunity of serial peripheral interface (SPI) interfaces to avoid RI114 failure.

Stage 7: Apply the suitable design solution

This stage is where the sixth element (implementation plan) in the A3LAMDA template is performed after the suitable solution has been identified from Figure 6-6. The suitable solution is identified based on confirmation and types of solutions (Table 5-9). According to Figure 6-6, solution no. 6 was chosen as it is very effective where it addressed the potential cause in the test issue. The EMC Test Engineer has undertaken a re-test procedure to solve the RI114 problem. This is related to the sixth activity presented in Figure 6-4. As a result, it passed the radiated immunity (RI) test. In case the test had failed, there are two options for the A3 team: first, by implementing another two proposed solutions (solutions 2 and 3) if the cause is still the same as that identified, but if a different cause appeared, the A3 team needed to go back to identifying and analysing the potential root causes and document them on the same A3LAMDA template.

Stage 8: Reflection on Action (ROA)

This stage refers to the second knowledge capability, knowledge capture which contains elements 8, 9 and 10 (What, So what and Now what) on the A3LAMDA template. The A3LAMDA owner successfully captured another lesson after the suitable solution is verified and documented it. Overall the lessons learned in element 8 are shown in Figure 6-7.

What

8. What is the knowledge?

No.	Lessons Learned
1	Need to consider effect of longer periods of interference. And specify in test plan if required.
2	Need to pay special attention to immunity of SPI interfaces
3	Software should deal with corruption on internal interfaces gracefully, recovering to previous where possible.

Figure 6-7: Reflection of What? of the RI114 Failure

Based on Figure 6-7, the A3 team have successfully generated and documented three design recommendations for future design reference and identified how this knowledge can be applied efficiently (reflection of So what). Therefore, three design recommendations were generated as shown in Figure 6-8 based on the captured lesson learned, and explained as follows:

- Design recommendation (Rec 1) based on first lesson learned: Specify in EMC test plan whether it is necessary to apply field for longer than the 2 second minimum. This knowledge identified is needed for EMC other design issue e.g.: test plan review.

- Design recommendation (Rec 2) based on second lesson learned: Review SPI interface for vulnerability to radiated fields. This identified knowledge is needed for circuit EMC design issues.
- Design recommendation (Rec 3) based on third lesson learned: Review software for graceful handling of errors on internal interfaces. This identified knowledge identified is needed for software EMC design issues.

So What

9. How can the knowledge be applied?

	Design Issues					
Design Rules (DR) / Design Recommendation (Rec)	**Circuit Design**	**PCB Layout**	**Interfaces**	**Software**	**Enclosure Design**	**Other**
DR 1 / **Rec 1** Specify in EMC test plan whether it is necessary to apply field for longer than the 2s minimum.						X
DR 2 / **Rec 2** Review SPI interface for vulnerability to radiated fields.	X					
DR 3 / **Rec 3** Review software for graceful handling of errors on internal interfaces.				X		

Figure 6-8: Reflection of So what? of the R114 Failure

Finally, at the final element on the A3LAMDA template, the A3 team identified where the three design recommendations (Rec) are needed based on the product development process (product's functions or activities) as shown Figure 6-9.

Now What

10. Where is the knowledge needed?

DR/Red	Function	Activity
Rec 1	Product Assurance	Create EMC test plan
Rec 2	Hardware design	Schematic review
Rec 3	Software design	Code review

Figure 6-9: Reflection of Now what? of the R114 Failure

Stage 9: Circulate the A3LAMDA report within the A3 team

The A3LAMDA owner circulated the completed A3LAMDA report within the A3 team by email in order to verify and finalise what had been documented and achieved during RI114 problem solving. This could lead to a new understanding and to obtain more personal/tacit knowledge after reviewing and sharing the complete A3LAMDA report amongst the A3 team.

Stage 10: Create design knowledge documentation for sharing and application

The stage is to ensure that the created and captured knowledge during the RI114 problem solving activities will be shared and organised effectively within the company. The hardcopy of the A3LAMDA reports can be shared, for example during meetings, in the EMC test area, or in the cafeteria. Whilst for the softcopy, the A3LAMDA reports could be shared as an attachment for each documented EMC design issue in the future. For example, after the A3 owner reviewing and searching the prior A3LAMDA reports related to the issue, will help him to understand previous decision making and recognise those who involved. As results, the process to identify the potential root cause and solutions will be quickly. The second enabler in the LeanPPD project, LeanKLC (Maksim, 2013) is responsible to compile the documented knowledge from the A3 thinking approach in knowledge database to ensure the knowledge is applied effectively.

Based on the second case study, the visualisation of the required data and appropriate tools structured on the A3LAMDA template aids the designers to identify and solve the EMC design problem of radiated immunity. Also, the reflection section enabled the A3 team to share and verbalise their personal knowledge either created during the case studies activities and from their previous design solutions (personal experience). The R114 failure has been successfully documented and solved by using the A3LAMDA template as a technique in the new A3 thinking approach. Thus, the aim of the case study 2 was achieved. The following sub-section explains the third case study namely as a partial solution and documentation.

Figure 6-10: A3LAMDA Report for Case Study 2

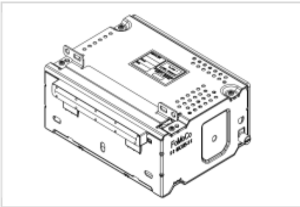
(Please Refer Figure 6-10 at the Folder of ‘Figures and Appendices’)

1. Team : MS, CC, RL, RW, IP and PB | Author: MS | Date: 27/02/2012 | Title: Lxy+ 123 DAB RI114 failure | A3 Report No.: MS/RI/02/1012

Look, Ask | *Model, Discuss & Act* | *Reflection*

2. Background

Product Type	X-Audio
Product Name	Vxxx Lxy+ radio
Product Code	BKxx1-xxxxx-01
Software No.	BKxx1-xxC0xx-01 (v08.X.X)
Printed Circuit Board No.	XYX01
Serial No. (S/N)	Z000XYZ; Z000ZYX
Customer Spec.	XYZ.01.0101



3. Current Condition

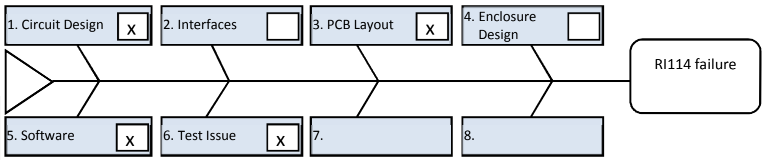
Test Request No.	TR.ELXX.XXXX	Functional Status	II
Test Type.	Radiated Immunity (RI 114)	Functional Performance Class	A
Other Information		Occurrence	All

Effect of Failure: Failure occurs only for interference applied for >15seconds. Self recovery seen for interference to 2s.

e-mail from PB:

Results obtained show that the audio drops out but recovers with a 2 second dwell at 580-610MHz and 720-760MHz. When a longer dwell time is used due to our thresholding routine the DUT does not self-recover. The Client X requirement is for a minimum dwell time of 2 seconds , longer dwell times may be necessary if DUT function response times are expected to be longer.

4. Root Cause Analysis



No.	Causes	Reason
1	SPI interface to DAB module vulnerable to interference.	Failure consistent with SPI communication failure. Issue not seen on DAB on Main Board variant with different filtering.
3	Layout issues on SPI lines	Layout is different to DAB on main board design.
5	Software does not handle SPI errors gracefully.	Return to FM mode is consistent with DAB source being deallocated.
6	Field being applied too long due to auto-thresholding.	If field is only applied for 2s, self recovery is seen.

5. Proposed Solutions

No	Solutions	Confirmation N/Eff	Confirmation S/Eff	Confirmation V/ Eff	Type of Solutions Cont	Type of Solutions Perm
1	Change filtering on Vxxx to be similar to that on DAB on main board.	X				
3	Review and change layout if appropriate.(Not changes yet identified)					
5	Modify software to stop communications to DAB module while SPI errors seen (not tried).					
6	Change test procedure to do non-audio test for level x so interference not applied for as long as 15s.			X	X	

BEFORE	AFTER
Unit drops to FM mode for 580-610MHz and 720-760MHz at Level 2. Typical thresholds at 80-90V/m	DAB Audio signal drops out but self recovers.
Design Ref. No.:	Design Ref. No.:

6. Implementation Plan

No Sol.	Tasks	Actions to Implement Proposed Solutions	Responsibility & Duration
6.1	Re-test	(Testing already done as part of investigation)	Test lab
6.2	document test process Change.	e-mail to test labs from EMC application engineer	MS– 1 day

Result: Ideally would explore more permanent solution. Temporary solution deemed low risk as interference at this level in the vehicle is unlikely.

Result Test Diagram

7. Prevent Recurrence

Questions for Prevent Recurrence	Y	N	Descriptions & Actions to Prevent Recurrence
1. Does the solution impact other EMC tests?	x		Same test process applied to all audio products Need to ensure that real underlying issues are identified.
2. Any consequences of possible solution cause to other products and/or processes?		X	

8. What is the knowledge?

No.	Lessons Learned
1	Need to consider effect of longer periods of interference. And specify in test plan if required.
2	Need to pay special attention to immunity of SPI interfaces.
3	Software should deal with corruption on internal interfaces gracefully, recovering to previous mode where possible.

9. Where is the knowledge needed?

Design Rules (DR)	Design Issues: Circuit Design	PCB Layout	Interfaces	Software	Enclosure Design	Other
DR 1 Rec 1 Specify in EMC test plan whether it is necessary to apply field for longer than the 2s minimum						X
DR 2 Rec 2 Review SPI interface for vulnerability to radiated fields.	X					
DR 3 Rec 3 Review software for graceful handling of eroors on internal interfaces				X		

10. How the knowledge can be applied?

DR / Red	Function	Activity
Rec 1	Product Assurance	Create EMC test plan
Rec 2	Hardware design	Schematic review
Rec 3	Software design	Code review.

Figure 6-10: A3LAMDA Report for Case Study 2

6.2.3 Case study 3: Partial Solution and Documentation

This case study was aimed at evaluating the use of the A3LAMDA template and to ascertain the starting point of knowledge capture even though not all its elements have been completed. Therefore, the EMC design problem of cluster which failed the radiated immunity (RI) test was solved by the EMC engineer. In contrast to the previous studies, the author was not involved in this case study. Two EMC engineers were involved as an A3 team for case study 3. The circuit design was identified as an EMC design problem and two potential causes was found. The first was noise being coupled into SBATT. This was because of the decoupling with the 10nF (capacitor unit); however, this proved not to be the cause. The actual cause was the pull down of the 68kohm resistor being high. In order to address this cause, one suitable solution has been proposed. After testing a few prototypes, the results show it has addressed the root cause of the problem, hence was identified as very effectively and permanently solved, as shown in the A3LAMDA report for case study 3 in Figure 6-11.

This report is shown as 80% complete as the elements number 9 (So what) and 10 (Now what) in the reflection section are not filled in (considering 10% for each element). This is due to the engineer’s opinion that two lessons learned in element number 8 (What) that were captured are not relevant to be formulated as a design rule or recommendation. From case study 3, it has been identified that new lessons and knowledge can be captured while completing the fourth and fifth elements or when not all elements in the A3LAMDA report have been completed. Thus the aim of case study 3 was achieved. The following sub-section explains the final case study, namely; generation and re-use of knowledge.

Figure 6-11: A3LAMDA Report Case Study 3

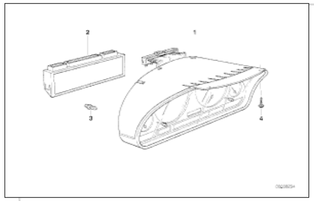
(Please Refer Figure 6-11at the Folder of 'Figures and Appendices')

1. Team : KG and AK | Author: AK | Date: 08/03/2012 | Title: XY-cluster failed EQ/IR01 free field tests due to the clock decrementing at 200V/m | A3 Report No.: AK/RI/03/2012

Look, Ask → | *Model. Discuss & Act* → | *Reflection* →

2. Background

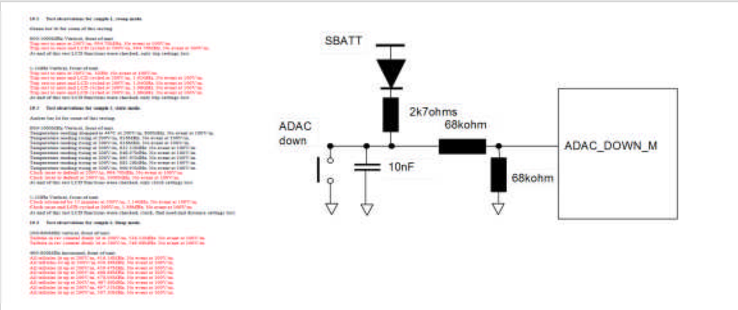
Product Type	Cluster
Product Name	XY Lx and Lz
Product Code	XY-Cluster
Software No.	0X.0Y.01
PCB No.	Pwb02121
Serial No. (S/N)	XXX012.01
Customer Spec.	XX-00-XYZ/--K
Other Information: At 200V/m the performance criteria for the clock	



3. Current Condition

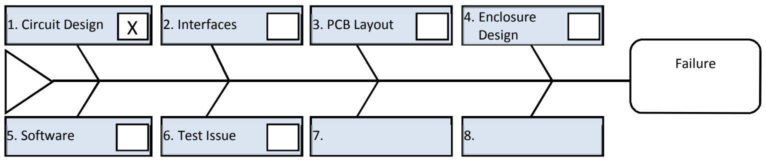
Test Request No.	TR.ELXY.0001	Functional Status	A
Test report No.	TR.ELYY.0012	Functional Performance Class	II
Test Type.	Radiated immunity	Occurrence	I
Other Information: EMC test plan is VETP0xxx XY-cluster.W:\EEDV\Product_Assurance\Driver Information\R\RXY-cluster\EMC\EMCTP\VETP0xxx XY-cluster EMC Test Plan v2 xxxxxxx			

Description of Failure:



4. Root Cause Analysis

Any Diagnosis:

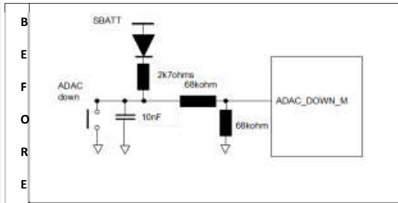


No.	Causes	Reason
1.1	Noise being coupled into SBATT	Decoupling with 10nF proved this was NOT the cause
1.2	Pull down of 68kohm resistor is a high	Halved resistance fixed the issue at 200V/m

5. Proposed Solutions

No	Solutions	Confirmation			Type of Solutions	
		N/Eff	S/Eff	V/ Eff	Cont	Perm
1.2	Potential divider uses too high a resistance in 68kohm resistance			X		X

BEFORE



Design Ref. No.:

PROPOSE

After Modification

Design /schematic Picture

Design Ref. No.:

6. Implementation Plan

No.	Tasks	Actions to Implement Proposed Solutions	Responsibility & Duration
1	Change resistance in	Change resistance in schematic	KG
2	Change value of resistance on current		

Result:

Result Test Diagram

7. Prevent Recurrence & Follow-up Action

Questions for Prevent Recurrence	Y	N	Descriptions & Actions to Prevent Recurrence
1. Does the solution impact other EMC tests?	X		The change to the resistance will require re-doing the BCI, free field and the handy transmitter test again.
2. Any consequences of possible solution cause to other products and/or processes?	X		The report will indicate that there was a change to the design so there will be a

8. What? What is the knowledge?

Lessons Learned
1. The EE connected the ADAC_down to 12V and the clock continued to decrement.
2. The EE connected the ADAC-down_M to 5V and the clock stopped decrementing over the 900MHz-1.2GHz.

9. So What? How can the knowledge be applied?

Type of Knolwedge : Design Rule (DR)/ Recomendation (Rec)	Design Issues: Circuit Design	PCB Layout	Interfaces	Software	Enclosure Design	Other
DR 1 / Rec 1						
DR 2 / Rec 2						
DR 3 / Rec 3						

10. Now What? Where is the knowledge needed?

DR / Red	Function	Activity

Figure 6-11: A3LAMDA Report for Case Study 3

6.2.4 Case study 4: Generating and Re-use of Knowledge

As a result of the EMC problem solving activities, knowledge is created. This needs to be captured to ensure the created knowledge can be distributed and shared with the right person, in the right place and at the right time by using the new A3 thinking approach. This case study refers to the knowledge captured from the reflections elements (What, So what and Now what) of the three A3LAMDA reports generated from case studies 1, 2 and 3. However, throughout the case studies, another three A3LAMDA reports have been generated by solving different EMC design problems and these reports are provided in Appendices 12, 13 and 14. Table 6-3 presents 12 lessons learned collected from the six A3LAMDA reports. This case study is about proving that the created knowledge is captured and documented using the A3 thinking approach and hence will distribute useful knowledge within the EMC product development process.

<table>
<tr><th></th><th>A3LAMDA Reports</th><th>Lessons Learned</th></tr>
<tr><td rowspan="6">Case studies</td><td>1</td><td>- If the recovery method from the conductor immunity event is not properly defined, the technician does not know what to do.</td></tr>
<tr><td rowspan="3">2</td><td>- Need to consider the effect of longer periods of interference and specify in the test plan if required.</td></tr>
<tr><td>- Need to pay special attention to immunity of SPI interfaces.</td></tr>
<tr><td>- Software should deal with corruption on internal interfaces gracefully, recovering to previous mode where possible.</td></tr>
<tr><td rowspan="2">3</td><td>- The EE connected the ADAC_down TO 12V and the clock continued to decrement.</td></tr>
<tr><td>- The EE connected the ADAC_down_M to 5V and the clock stopped decrementing over the 900MHz-1.2GHz.</td></tr>
<tr><td rowspan="6">Appendices</td><td>12</td><td>- During the pre-DV, the test was not done correctly as only the front face was tested. If the engineer had had this information earlier then, then the engineer would have discussed this with the client before validation started and would have negotiated testing to the G specification requirements.</td></tr>
<tr><td rowspan="3">13</td><td>- Support equipment is a key to measuring the results.</td></tr>
<tr><td>- Problem introduced because support kit changed from first test phase.</td></tr>
<tr><td>- Support kit should be validated before use (this case would need to have done a radiated emissions test to check the support kit!)</td></tr>
<tr><td rowspan="2">14</td><td>- Poor grounding at the antenna connector made the unit more vulnerable to radiated immunity.</td></tr>
<tr><td>- Process for supplying units for test needs to ensure quality of build etc.</td></tr>
</table>

Table 6-3: List of Lessons Learned Captured from A3LAMDA Reports

The twelve lessons learned shown in Table 6-3 guided the EMC engineers to generate design recommendations which have been considered important for future design reference, as shown in Table 6-4. For example, the first lesson learned is to define the recovery method from the conductor immunity so the technician knows what to do. As this lesson learned is important to consider in future, the EMC engineer has generated it as a design recommendation which is that the EMC test plan clearly defines the recovery sequence after the immunity event. Table 6-4 presents the element of 'So what' in the reflections section in which eight design recommendations from six A3LAMDA reports are generated. Also, each of the design recommendations has been identified by the related design issues. For example, design recommendation 3 (Rec 3) at case study 2 is related to the design issues of circuit design. The A3LAMDA report for case study 3 was not completed, therefore it has not been presented in Table 6-4. Although the A3LAMDA report in Appendix 13 has provided three lessons learned, the EMC engineer has generated only one design recommendation as the lessons are related. From this table, none of lessons learned was generated as a design rule.

		DR/ Rec	Design Rules (DR)/ Recommendations (Rec)	Design Issues					
				Circuit Design	PCB Layout	Interfaces	Software	Enclosure Design	Other
Case studies	1	Rec 1	EMC test plan clearly defines recovery sequence after immunity events.						X
	2	Rec 2	Specify in EMC test plan whether it is necessary to apply field for longer than the 2s minimum.						X
		Rec 3	Review SPI interface for vulnerability to radiated fields.	X					
		Rec 4	Review software for graceful handling of errors on internal interfaces.				X		
Appendices	12	Rec 5	The pre-DV test must be correctly and fully performed before validation.	X					
	13	Rec 6	Check that support kit is the same before testing, or re-validate any new/changed kit.						X
	14	Rec 7	All cable shields should have good and preferably 360 degree connection to chassis.					X	
		Rec 8	Pre-test checklist to ensure that all screws are tightened to correct torque etc.						X

Table 6-4: Design Recommendations Generated from A3LAMDA Reports

The final element of the reflections section (Now what) on the A3LAMDA template is to define where the knowledge can be applied within the EMC product development process in the collaborative company. The eight design recommendations shown in Table 6-4 have been identified and where they could be used for specific function(s) and activities, as presented in Table 6-5.

Design Recommendations (Rec)	Function	Activity
Rec 1	EMC Application Engineering	EMC Test result review
	EMC Test Engineering	EMC Report Writing
	EMC Product Assurance	EMC Test Plan Generation
Rec 2	Product Assurance	Create EMC Test Plan
Rec 3	Hardware Design	Schematic Review
Rec 4	Software Design	Code Review
Rec 5	Product Assurance and Software Validation	Execute Test plan
	Electrical Engineering	Develop Verification Test Plan
Rec 6	Product Assurance	Build or Supply Support Kit
Rec 7	Mechanical /Electrical Engineering	Mechanical /Electrical Design
Rec 8	Product Assurance and Software Validation	Execute Test plan

Table 6-5: Knowledge Allocation within the EMC Product Development Process

The fourth case study has successfully proved that knowledge is generated and re-used through problem solving activities within the A3 team. Adopting a simple A3LAMDA template allows the visualisation of the useful knowledge to be quick and easy. In addition, it has been proved in the reflection section based on questions (what-so what-now what) that the template aided engineers to capture and verbalise the useful knowledge in effective way. Hence the useful knowledge is provided and distributed to the right place and person at the right time – hence aided the generation of knowledge driven design. This has developed a knowledge based environment which supports the second key principle of the LeanPPD model, as shown in Figure 1-2. The following describes the second validation method use to validate the A3 thinking approach through industrial experts' judgement.

6.3 Industrial Expert Judgement

Expert judgements have been captured immediately throughout the development of the A3 thinking approach in those companies that participated in the data collection and case studies. The validation method for industrial experts' judgement was divided into two parts as follows:

a) Initial validation – whilst developing the A3 thinking approach and designing the A3LAMDA template. The initial validation was performed during focus groups in the collaborative company, as shown in Table 4-3. The expert judgements were made with regard to the foundations and logic of the A3 thinking approach, as presented in Chapter 5, to support problem solving in product design.
b) Final validation – validating the process of use and also the final version of the A3LAMDA template which has been fully developed. This refers to the contribution from the companies whilst performing the case studies and semi-structured interviews.

The following are some examples of the questions which helped the experts to voice their judgements about the A3 thinking approach:

- How logical is the thinking approach as an approach to solve problems in product design?
- Do you think the template is easy to follow and an effective report for documentation and communication?
- Do you think the elements are comprehensible?
- How do you think the performance of the A3 thinking approach compares with your current approach to solving design problems?
- Please indicate which elements you think are most important and interesting.
- Please comment on the reflections section in order to capture the knowledge.

The details of the industrial experts are presented in Table 6-6. Both the initial and final validations are given by 11 industrial experts from the collaborative company and the remainder are from the experts involved during the semi-structured interviews.

Experts	Key Roles	Years of Experience
1	Electronic Engineer	9
2	EMC PCB Design Technical Professional	6
3	EMC Application Engineer	7
4	Continuous Improvement	10
5	Continuous Improvement Manager	8
6	EMC PCB Design Technical Professional	6
7	EMC Application Engineer	7
8	Lead Engineer	5
9	Radio Frequency & Antenna Specialist	12
10	EMC Test Engineer	10
11	Radio Electrical Engineer	9
12	Project Manager	15
13	Project Manager	8
14	Product Design and Development	10
15	Manufacturing	25
16	Purchase	8

Table 6-6: Details of Industrial Experts Judgements

The following explains the collated results from the experts' judgements captured from the initial and final validations. These were classified into three key judgements on: the elements structured in the A3LAMDA template; the A3 thinking approach to solve design problems; and, generating and capturing knowledge documented in the A3LAMDA template.

6.3.1 Experts' judgements on the elements structured in the A3LAMDA template

The expert judgements on the elements structured in the A3LAMDA template are summarised in Table 6-7. Most of the judgements agreed and provide good feedback on the specific elements structured in the A3LAMDA template, such as containment, root cause analysis, prevent recurrence and also the elements for the reflections section.

Experts	Experts Judgements
1, 2, 4, and 9	• The flow in the A3LAMDA template is much simpler and easy to follow.
1	• "A new A3LAMDA template is also provided with the temporary solution (containment) section where this sometimes is necessary because it's cheaper and quicker." • "The engineers always perform testing to confirm the root cause with temporary solutions, so it will be more helpful to capture this information in an A3LAMDA template."

2	• "The flow of the elements in the A3LAMDA template is quite logical and makes sense; it covers all the processes of problem solving." • "This kind of classification on root cause types is pretty good." • "The reflection of capturing knowledge in the A3LAMDA template is helpful." • "In the reflection section; 'where the knowledge is needed?' is the most important part."
3	• "The containment in the proposed solutions is a good idea." • "The proposed solution element is important where it documents the confirmation and the status of the solution (containment/permanent). Sometimes we rush in to solve the problem. I like this element."
4	• "The visualization of the design before and after modification is good." • "Good to provide a space where the designer can write the design reference." • "The flow in A3LAMDA template is good." • "The link between the amount of root cause analysis and proposed solutions is good."
5	• "The question in the prevent recurrence element is interesting, as it is important for us in solving the problem."
6	• "The elements provide the engineer with a consistent methodology." • The elements in the A3LAMDA template are comprehensible hence it helps the engineers to know what should be documented.
7 and 9	• The LAMDA learning cycle is easy to remember. Even we as engineers sometimes have to go and look to test a chamber and ask thousands of questions of the EMC tester to identify the problem causes and to solve it. I totally agreed if this cycle will be implemented formally in the problem solving approach.
9, 15 and 16	• All the elements are comprehensible and the prevent recurrence, which is a must. The reflection is the biggest advantage.
11 and 12	• The A3LAMDA is beyond just solving the problem.

Table 6-7: Experts' judgements on the elements structured in the A3LAMDA template

6.3.2 Expert's judgements on the A3 thinking approach to solve design problems

Table 6-8 presents the experts' judgements on the A3 thinking approach to solve design problems. It also shows the rationale and relevance of the A3 thinking approach to solve problems in product design. According to the table, the author has identified that all the experts agree of the relevance and logic of the A3 thinking as an approach to solving problems in product design. Furthermore, the size of the A3LAMDA template and its simplicity are two of the advantages of the A3 thinking approach.

Experts	Experts' Judgements
All	• The experts agreed on the logic of the A3 thinking approach to support product design.
2	• "It is very interesting to have the template; currently when facing complex failures, they used to attach many documents, but now it will be restricted to A3 sized paper. Agree with this idea." • "All problems should be solved using the A3 thinking approach."
3	• "The advantage of the A3 thinking approach is the flow of lessons learned and then shared within the team".
4 and 5	• The A3LAMDA template enables the future designer to trace the failure easily and see how the solution is delivered, which makes them break it down into a new understanding. • "The link between 'what is before' and 'what is after' in the A3LAMDA template is its biggest strength."
5	• A3 Thinking is not only a problem solving approach, but a good communication tool. • Agree with the logic of the A3 thinking approach although there are duplications in putting the data into the A3LAMDA template. e.g.: design layout in current condition element and design before modification in proposed solution element.
5, 6 and 9	• The A3LAMDA template is quite good.
All	• By providing the reflection section, the A3 thinking approach will be a good problem solving approach.
7	• "Yes, I like A3 thinking approach."
7 and 8	• It is simple and I like the size.
8	• The A3 thinking approach is not only solving the problem but is an effective communication tool within the team. Especially when you look at all the information on an A3 sized sheet of paper. • Sometimes I have problems in documenting the failure after testing, but with the A3 thinking approach, the important and necessary information to document the failure is finalized. This makes my job easier.

Table 6-8: Experts' judgements on A3 thinking approach to solve design problems

6.3.3 Experts' judgements on generating and capturing knowledge documented in the A3LAMDA report.

In Table 6-9, the experts' judgements in generating and capturing knowledge documented in the A3LAMDA template are presented. They identified the benefits of reflection which allows sharing, and hence capturing the knowledge among the design team. This has also been recognised by the collaborative company as a value for product development in the future.

Experts	Experts' Judgements
1	• "It will be good to clarify the knowledge."
2	• "The reflection section is the most important part where it will be easy to pull out the knowledge into the design checklist." • "Design rules and design recommendations structured in the reflection section, will help to categories the knowledge into different parts of the checklist."
3	• "Knowledge created from the A3LAMDA template is effective when it narrows down the content and is more objective." • The eighth (What) element in the reflection section encourages problem solvers to list their lessons learned from problem solving before jumping into design rules which can be quite dangerous. This also to improve the quality of the knowledge to be provided and where the knowledge is needed in future (tenth element).
5	• "Agree that knowledge could be shared using the A3LAMDA report." • "The new A3LAMDA is brilliant by solving the problem by capturing and documenting the personal knowledge."
6 and 8	• The reflection section is not only good for the designers as a future reference but also advantageous to the company by documenting the knowledge from the heads of experts.
7	• "I preferred the printed A3LAMDA during the discussion. It helped me to digest the important information on the front-page before reaching a solution. Yes, I think it will be a good communication tool where you are sharing your expertise (knowledge) within the team."
13-15	• "We used the 8D approach but we don't have time to follow all the requirements (elements). But this (A3LAMDA template) is front-end documentation and could be easy for us to follow."
10 and 12	• "The A3LAMDA template is almost the same with the 8 Disciplines (8D) approach, but the reflection section in A3LAMDA is brilliant."

Table 6-9: Experts' judgements in generating and capturing knowledge

According to the feedback, it has been verbally verified that the A3 thinking is a simple and effective problem solving approach for product design and hence will support lean product and process development by documenting and visualising the created knowledge within knowledge based environment. However, most of the experts raised the same revision of the A3LAMDA template, which is that developing A3LAMDA software on a computer system could be advantage.

The LeanPPD industrial workshops in Cranfield University have given opportunities for the author to gather expert judgements from experts who had never been associated with the research and these are presented in the following section.

6.4 The LeanPPD Industrial Workshops

The LeanPPD industrial workshops were performed in January 2011 and June 2012 at Cranfield University, UK. More than 80 participants, mainly from manufacturing industries from all over the world, such as Rolls-Royce, Airbus, and McLaren Automotive registered for the workshops. These have become big opportunities for the research in capturing feedback according to the research's rationale and relevance to support problem solving in different manufacturing companies. During a half hour presentation for each workshop, the ideas of the A3 thinking approach and the A3LAMDA template were explained. In addition, several examples of the A3LAMDA reports were presented and demonstrated. Positive feedbacks were captured within a group of people who had not been associated with the research study. At the end of the workshops, all the participants were provided with a one-page questionnaire. The author only selected two questions in the questionnaire related to this search highlight as the following and Figure 6-12 shows the results.

- Question 1 (Q1): Please evaluate the topic of the A3 thinking approach.
- Question 2 (Q2): Which of the following LeanPPD enablers are you mostly interested in?

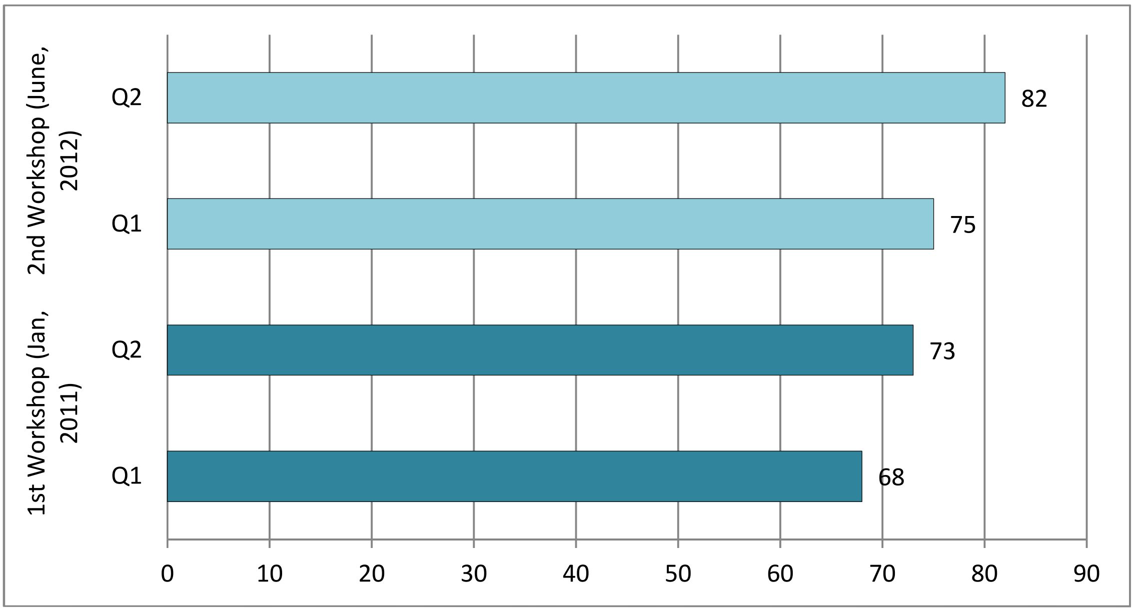


Figure 6-12: The Results from LeanPPD Industrial Workshops

According to the above figure, the results of the A3 thinking approach show the increment of percentage for both questions 1 and 2 at the second workshop. The first workshop which was performed in 2011 had a lower percentage as the author presented only the foundation and logic of the A3 thinking approach based on the analyses gathered from the literature reviews and data collection from industrial perspectives. Whereas the second workshop, details of the process were explained, the final version of the A3LAMDA template was presented and several examples of the A3LAMDA reports were demonstrated to the participants.

As explained in Chapter 4, Table 4-3 represented the summary of the interviews from all the respondents. Their feedback has been categorised into endorsement and reservations. Therefore, Table 6-10 shows the improvements that have been achieved during validation to address each of the reservations.

6.5 Chapter Summary

Section 6.1 briefly described the validation methods from which two suitable methods were chosen for this research; case studies and expert judgements. Section 6.2 explained four case studies which were identified in order to verify and validate the application and performance of the A3 thinking approach; documenting a solved problem, solving the actual problem, partial solution and documentation; and generating and reusing knowledge. Section 6.3 explained the initial and final validation of expert judgements. The ideas are to capture the logic and relevance during and after development stages of the A3LAMDA template and the new A3 thinking approach. Section 6.4 described the validation of the A3 thinking approach within LeanPPD industrial workshops. These have offered great opportunities for the author to capture feedback from multiple companies and industries. In the next chapter, the key research findings, research contributions and limitations are further discussed as the final chapter of this thesis.

Respondents	Reservations	Improvements
A	a) A new A3 report is interesting because of being one-page; however, does that A3LAMDA report have enough space? b) Who will be responsible for transferring knowledge from a new A3 report to the design checklist?	a) Yes, there is enough space after the examples of the A3LAMDA reports were developed by the designers in the collaborative company. b) The person responsible for transferring knowledge to the design checklist is the knowledge expert which not covered in this thesis.
B	a) It would be good if the tool to transfer the knowledge from the A3LAMDA into the checklist were automatic. b) The necessity of a picture in a new A3LAMDA report may depend on different products. The point is whether or not the picture will provide useful information. If the way to search the related product picture and put in an A3 report is inconvenient, it will not be able to encourage the engineer to use a new A3 template. c) The picture put into a new A3 template would be restricted by the size, sometimes we need a big picture; could a new A3 template have the function to zoom in a bigger picture? d) If I'm struggling to find the pictures of the product, I will not use this new template. e) A new A3 template should be developed in Java.	a) With the simple structure of the elements in the A3LAMDA template it would be easy to pull out the knowledge into the design checklist. b) The product picture in the A3LAMDA template is important for visualisation purposes, whilst, the most important pictures that need to be visualised are those of the result and design before and after the modifications. c) The A3LAMDA template was developed using Ms Word Developer as explained in Section 5.8. The picture cannot be zoomed; however, only 2 seconds are needed to upload the picture from the Pictures database. d) If there are less than 10 products in the company, these pictures can easily be documented in a Pictures database by the initial designer who is using the A3LAMDA template. e) The A3LAMDA report was developed using Ms Word Developer as an alternative for the company. The research focuses on the process and tool in problem solving, but not providing the software. However, the company can also enhance the tool or process into other programs.
C	a) Unfortunately I found the new A3 report very difficult to fill in because there was so much duplication of the same information and the constriction of the space for inputting a valid explanation and the associated diagrams. b) The reflection section was difficult to understand and to fill-up until somebody explained it to me.	a) The duplication has been solved by providing guidelines and key headlines to help the designer to understand each of the elements. This has been addressed in Section 5.7. b) The A3LAMDA template was modified and more spaces are now provided for inputting explanations or diagrams.
D	How to insert a picture into a new A3 template in 4-5 seconds. Without pictures in a new A3 template, it will be no different from other approaches.	Inserting a picture into the A3LAMDA template by using Ms Word Developer, only took 2 seconds. In addition, rows have been placed for the designer to insert a design reference on the bottom line for each of the designs before and after modifications in the A3LAMDA template as shown in Figure 5-3.
A, B, C & E	The linkage between the elements in a new A3 template is very good if it can conduct automatically.	At present, no software has been developed to link the elements in the A3LAMDA template. This will be a potential future work.

Table 6-10: Improvements on Reservations from Collaborative Industries

Chapter 7

7 DISCUSSION, CONCLUSIONS AND FUTURE WORK

This chapter consists of five sections; in Section 1 the research results from the adopted research methodology, A3 thinking approach development and validation of the developed approach based on four case studies are discussed. Research limitations are presented in Section 2 and key research contributions are highlighted in Section 3. The conclusions and suggestions for future research are provided in Sections 4 and 5.

7.1 Discussion of Research Results

7.1.1 The Research Methodology

In order to ensure the results from the research methodology will not be distorted, four data collection methods were used: literature and industrial documentation reviews, semi-structured interview, direct observation and focus group. The development of the A3LAMDA template was started from the literature review using several problem solving approaches and identifying which ones are capable of being considered and adapted in product design and development. This identification is based on a non-computational/statistical approach and also provides a template. Five features have been identified based on the knowledge management capabilities of creation, capture and sharing which led to identifying the limitations of current problem solving approaches (Table 5-1). The semi-structured interviews were useful and were all conducted face-to-face; however, they did not capture the actual situation of the related concerns. Inspection of the documents and direct observation at the collaborating company helped the author to investigate and analyse physically the current practices of the problem solving approach and process. By assembling focus groups, the ideas of the proposed approach to address the limitations and to offer more benefits in product design were realised by the engineers in the collaborating company. In addition, the captured judgements for the A3 thinking approach by industrial experts and during LeanPPD industrial workshops reduced the possibility of bias and showed the novelties of the A3 thinking approach.

7.1.2 A New A3 Thinking Approach Development based on the A3LAMDA Template

There are huge numbers of approaches to solve problems but only a few of them apply in product design. In order to support lean product design and development, this thesis needs to ensure the creation and capture of knowledge in a lean environment. Therefore, there is a need to have a new problem solving approach and process for product design based on learning organisation. This has facilitated the actual problem solving process of: problem definition, identification of the root-cause analysis, ideas or solutions generation, prevention of problem recurrence and endorsement of the learning process. All these processes could be usefully to be integrated as a single approach not only to solve the problems but also to create and capture the knowledge in a dynamic way. This has been achieved when the EMC problem has been documented and solved, and the created knowledge captured and translated into design recommendations or rules. Hence this useful knowledge is available to share for future projects that will support decision making and prevent a recurrence of similar design problems. The capabilities of knowledge creation, capture and sharing have all been integrated in the new A3 thinking approach aimed at addressing all the features (Table 5-1). These have been proved through the validation method, industrial case studies of the A3 thinking approach and are explained in the following sub-section.

7.1.3 A3 Thinking Approach Validation – Case Studies

The results from the validation in the collaborative company show that the A3 thinking approach aided the generation of knowledge driven design to support decision making in the future. This discussion of the validation's results is based on four industrial case studies as follows:

Case study 1 was the first time the newly developed A3LAMDA template had been used. It aimed at making the engineer in the collaborating company familiar with the A3 thinking process. For this reason, case study 1 was designed to use the data from already solved design problems which has been recorded in different EMC documentation (EMC test report, problem solving report and 8 Disciplines (8D) approach). The data was captured and transformed in the A3LAMDA template. The author worked with the EMC design technical professional (expert 1) to fill in the A3LAMDA report and to evaluate the ease of use of the template as well as its impact on capturing and sharing the created knowledge. This case study convinced expert 1 of its value within their application as the template is easy to use and simple to follow. Case study 1 also helped to obtain feedback in order to enhance the design of the A3LAMDA template then improve the process of solving design problems. Within this case study, it was identified that;

- The process of documenting a paper-based A3LAMDA template is quite challenging, mainly for inserting the product or design pictures. Thus, the A3LAMDA template in Microsoft word developer, as presented in Section 5.8 has been used.
- Huge effort and time had previously been taken to document the solved design problem in different EMC documentations.
- It is difficult to retrieve the valuable lessons learned that have been created in previous problem solving activities, from different EMC documentation.

Case study 2 was aimed at solving the actual EMC problem by employing the process of using the A3 thinking approach explained in Section 5.7. This case study also aimed to show that the proposed A3 thinking approach addresses all the features presented in Table 5-1 and explained the following features which are based on A3LAMDA report shown in Figure 6-10.

a) Visualise the necessary process and information to address the problem, by using the product picture, fish bone diagram and table helped designers to address directly the cause and effect of the audio that failed radiated immunity test. Four possible causes have been identified related to circuit design, PCB layout, software and test issue and the table consists of causes and reason encouraged designers to perform the 5 Whys technique.
b) Present the generation and implementation of the solutions – the EMC experts have proposed four potential solutions to address the root causes and hence to solve the problem. The suitable solution (No.6) has been chosen based on the confirmation and type of solutions which are very effective but considered to be a containment solution. The presentation of the alternatives solutions will helped future designers to generate new ideas in order to solve the problems.
c) Provide the process of the learning cycle for knowledge creation – based on the LAMDA learning cycle, the problem systematically guided the EMC experts to solve the problem. This has been achieved where the seven elements structured in the knowledge creation section have been completed.
d) Present a reflection on the lessons learned – three lessons learned were captured while identifying the possible causes and proposing alternatives solutions, hence transformed it into three design recommendations:
    1. Need to consider the effect of longer periods of interference and specify in test plan if required.
    2. Need to pay special attention to immunity of Serial Peripheral Interface (SPI).
    3. Software should deal with corruption on internal interfaces gracefully, recovering to previous mode where possible.
e) Create useful knowledge concisely from those actions to be shared and communicated – three lessons learned were transformed into three design recommendations related to the circuit and software design issues which have been considered as follows:

1. Specify in EMC test plan whether it is necessary to apply field for longer than the two seconds minimum – for other design issues.
2. Review Serial Peripheral Interface (SPI) for vulnerability to radiated fields – for circuit design issues.
3. Review software for graceful handling or errors on internal interfaces – for software design issues.

This useful knowledge will be compiled as a Design Statement Checklist (DSC) in a knowledge database for future work. DSC will be a standard set of structured statements to prevent the recurrence of similar design problems and to help the designers to adopt the expected EMC test results in future.

Case study 3 was aimed at evaluating the use of the A3LAMDA, even though not all its elements have been completed. This uncompleted A3LAMDA report still can capture the created knowledge in problem solving as long as the solutions are proposed. The author was not involved in this case study, thus the A3LAMDA report for case study 3 was produced by the EMC engineer and then sent to the author to review and verify the accuracy of using the A3LAMDA template within the A3 thinking process. After the A3LAMDA report's verification, it was shown that the knowledge creation section was completed, but not the knowledge capture section (as shown in Figure 6-10). However, as the knowledge was documented, it will always be possible for the designers to refer to this A3LAMDA report, and hence reflect on the design solution and extract useful knowledge for future re-use. This could be done by either the same design team who were involved in solving the problem or by different persons who are knowledgeable about the developed A3 thinking process based on A3LAMDA and the EMC design issues.

Case study 4 was aimed at collecting all the knowledge created and captured from the documented A3LAMDA reports throughout the research. Six A3LAMDA reports have been collected which provide twelve lessons learned, as presented in Table 6-3. These lessons were formulated as eight design recommendations (Recs) and are shown in Table 6-4. This useful knowledge will be compiled as a Design Statement Checklist

(DSC) in the knowledge database which is a research deliverable of another PhD student; Mr. Maksimovic related to the LeanKLC enabler (Maksimovic, 2013). From these results, the aim of this case study was accomplished where the reflection section allowed the EMC experts to capture the created knowledge during problem solving so that it can be shared in the future.

7.2 Traditional versus New A3 Thinking Approaches

The traditional A3 report consists of seven elements and uses the PDCA learning cycle for continuous improvement in the traditional A3 thinking approach. Whilst the A3LAMDA report as a technique in the new A3 thinking approach, consists of ten elements and is guided by the LAMDA as a cycle of knowledge creation suited to support lean product and process development. Several key conclusions are identified after a comparison between the traditional and new A3 thinking approaches:

- The traditional A3 thinking approach is widely applied on the manufacturing shop-floor. The new A3 thinking approach is designed to support problem solving and to be implemented in product design.
- Both traditional and new A3 thinking are the approaches for problem solving, communication, collaboration and documentation. However, the new A3 thinking entails a greater range of applications as an approach for knowledge capture, lessons learned documentation (failure and success), tacit knowledge sharing, knowledge documentation and as a useful knowledge source.
- As a communication tool, both approaches are effective based on their size and simplicity; however, reflection on the A3LAMDA template enables the designer not only to listen and discuss but to capture and document any lessons that might be useful and significant to be considered in current or future design projects.
- As a problem solving approach, the traditional A3 report only focuses on solving a problem whereas the A3LAMDA is not only focusing on solving a problem but also on capturing and documenting the useful knowledge.

- The traditional A3 report documents any results of success, but in the new A3 thinking approach, learning from failure is also recorded as this is a much better teacher than success (Madsen and Desai, 2010; Storey and Barnett, 2000) and therefore also vital to capture and document.
- Both the solution and captured knowledge in the A3LAMDA template create useful knowledge to be structured as a DSC to be shared and applied in future projects.

7.3 Research Limitations

This section explains the research limitations of the research methodology, A3 thinking approach development and validation, which have been identified throughout the research study.

Bias is a major weakness in qualitative research but impossible to eliminate. Some necessary actions were taken in order to reduce bias for this research as explained in sub-section 2.2.5, such as prolonged involvement, triangulation, peer debriefing and support, member checking and audit trail. Within time and resource constraints, some additional proactive actions were taken: 1) involvement of the author in the experts and case studies selections; 2) proper planning of the case studies within the participated stakeholders; 3) effective communication with the design experts to ensure the research's requirement were clearly determined and satisfied; and 4) use of multiple tools for data collection, such as voice recorder and digital camera, during most of the interviews, meetings and industry visits. In order to mitigate bias that can affect the validity and reliability of the results, several actions have been taken: first, a number of methods have been used to collect the data, such as documentation review, semi-structured interviews, direct observation and focus groups at the collaborating company; second, the author has provided reports, as a summary of the obtained results from the data collection, which have been well recorded and analysed.

The development of the A3LAMDA template and A3 thinking approach are derived from discussions, interviews, meetings and workshops with design experts and engineers from the collaborating companies. The limitations have been identified where the A3LAMDA template has to be implemented by a design expert on problem solving with a good understanding of the design process. This is to avoid any misjudgement of the inputs to the A3LAMDA template. A second limitation is the small number of participating respondents during the industrial field study; 25 for the interviews and five stakeholders for the focus groups. However, they have enough experience in research areas. Finally, limited knowledge of lean product and process development seems to have been a big issue for the collaborating company.

The approach has been validated only in the automotive sector through four industrial case studies within electromagnetic compatibility (EMC) design tests. The limitations during the A3 thinking approach validation have been identified: 1) Only one company in the automotive sector has been involved for the validation of the proposed approach; however, expert judgements have been captured and recorded during LeanPPD industrial workshops from both academic and industry experts from multiple sectors who had not been associated with the research in the collaborating company; and 2) the experts from the LeanPPD workshops have different expertise and backgrounds which naturally affects the results with their different points of view about the new A3 thinking approach.

7.4 Research Contributions

The key research contribution is the development of a new A3 thinking as a product design problem solving approach to aid the generation of knowledge driven design to support decision making within a LeanPPD environment. This key contribution relates to the capability of knowledge creation, capture and sharing towards an effective solution in a problem solving activity – hence, addressing the challenges that hinder the full utilisation of the created knowledge, as explained in Section 1.1. The contributions to knowledge are listed as follows:

1) An identification of knowledge management capabilities for problem solving in order to aid the generation of knowledge driven design, bearing in mind the limitations of the knowledge creation, capture and sharing using the current problem solving approaches to support product design.
2) A generation of a new A3 template based on the customised elements gathered from the inter-relation analysis to solve problems in product design. Also, as a simple problem solving documentation template, it allows the designers to retrieve knowledge easily.
3) An adoption of reflection practice structured on the A3LAMDA template for capturing the created knowledge to be shared and applied for future design projects in order to support decision making.
4) A development of a novel A3 thinking approach based on the A3LAMDA template formulated from addressing the different features of current problem solving approaches – hence supporting lean product and process development.
5) A development process of using the A3 thinking approach based on the A3LAMDA template to support and guide designers, engineers and problem solvers who wants to implement the new approach in an effective and efficient way.

7.5 Conclusions

According to the research results and achievements, research conclusions are presented as follows:

1) Problem solving is a crucial skill in product development. The lack of effective decision making at an early design stage will affect productivity and increase costs and the lead time for the other stages of the product development life cycle. This research has provided the new A3 thinking problem solving approach to aid the generation of knowledge driven design to support decision making at an early stage in product development-product design.

2) This thesis provides an approach and process of continuous improvement by systematically solving design problems and then capturing the created knowledge to be shared for future design reference. Hence it is contributing to the key principles of the LeanPPD of knowledge based environment and continuous improvement.
3) There are many problem solving approaches, but only a few of them have been used in product design. This is due to the activities of problem solving in product design being complex and requiring scientific knowledge in order to solve design problems. Therefore, there is a need for a new problem solving approach that supports a knowledge based environment which is the main output of this thesis.
4) Analysis of current problem solving approaches shows that there are several elements and tools in different approaches that could be adapted and customised to develop a new approach. Therefore, the new A3 thinking approach has entailed all the elements and tools, such as text, diagrams, pictures and tables which helped the designers to identify and solve a problem.
5) In order to ensure the performance of solving design problems, the knowledge creation cycle, LAMDA, which has been introduced for lean product and process development, has been introduced and associated with the new A3 thinking approach. It helped and guided the designers to perform knowledge creation to improve problem solving.
6) Several problem solving approaches are employed, but none of them address the integration actions of visualising, solving, learning, reflecting and creating. The new approach was developed with the integration of these actions to support knowledge driven design.
7) The A3LAMDA template was developed based on ten new elements gathered from the inter-relation analysis and requirements from the collaborating company. The template consists of two sections – knowledge creation and capture.

8) The development of the new A3 thinking approach based on the A3LAMDA template is aimed not only at solving design problems but also at providing a way to capture the created knowledge, hence to be shared in order to support decision making in the future.
9) Four case studies have demonstrated and validated the proposed A3 thinking approach in a real working environment which is effective that the new A3 thinking approach supports the LeanPPD environment.

7.6 Future Work

The potential areas of future work based on the research's discussions are identified as the following:

1) To have a further detailed analysis of the proposed A3LAMDA template that could be modified to be applied to different process and industrial sectors.
2) To have further studies into re-using the captured knowledge to support design decision making to prevent problem recurrence. This is outside the scope of this research work due to research constraints (e.g. time) and limitations.
3) In order to have a comprehensive knowledge based environment based on the created and captured knowledge, more A3LAMDA reports need to be produced and managed to support new design projects.
4) To develop a smart application of the A3LAMDA template. Although the author has designed the concept of a database using Microsoft Word Developer, the development of the smart application will need to be advanced.

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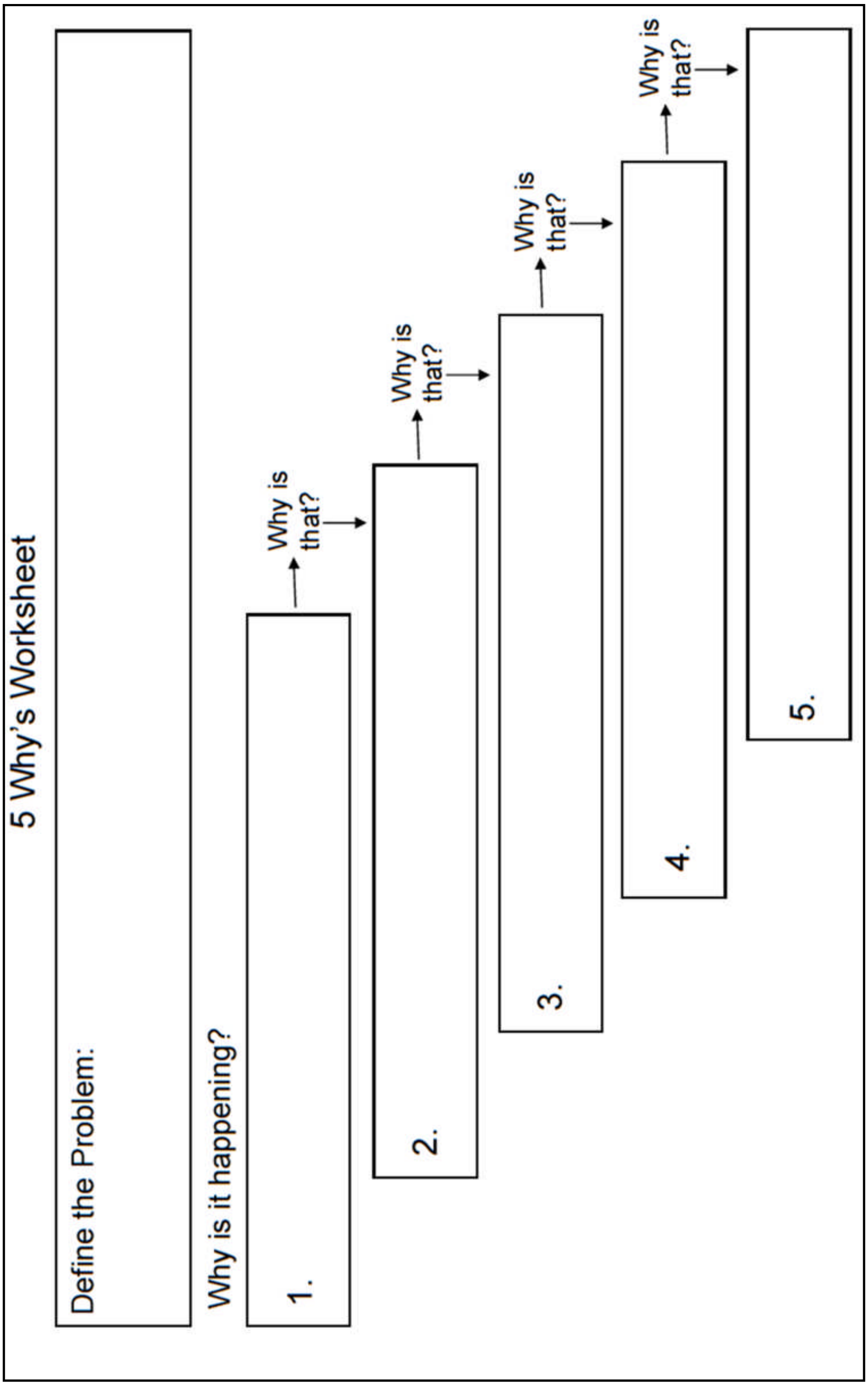
APPENDICES

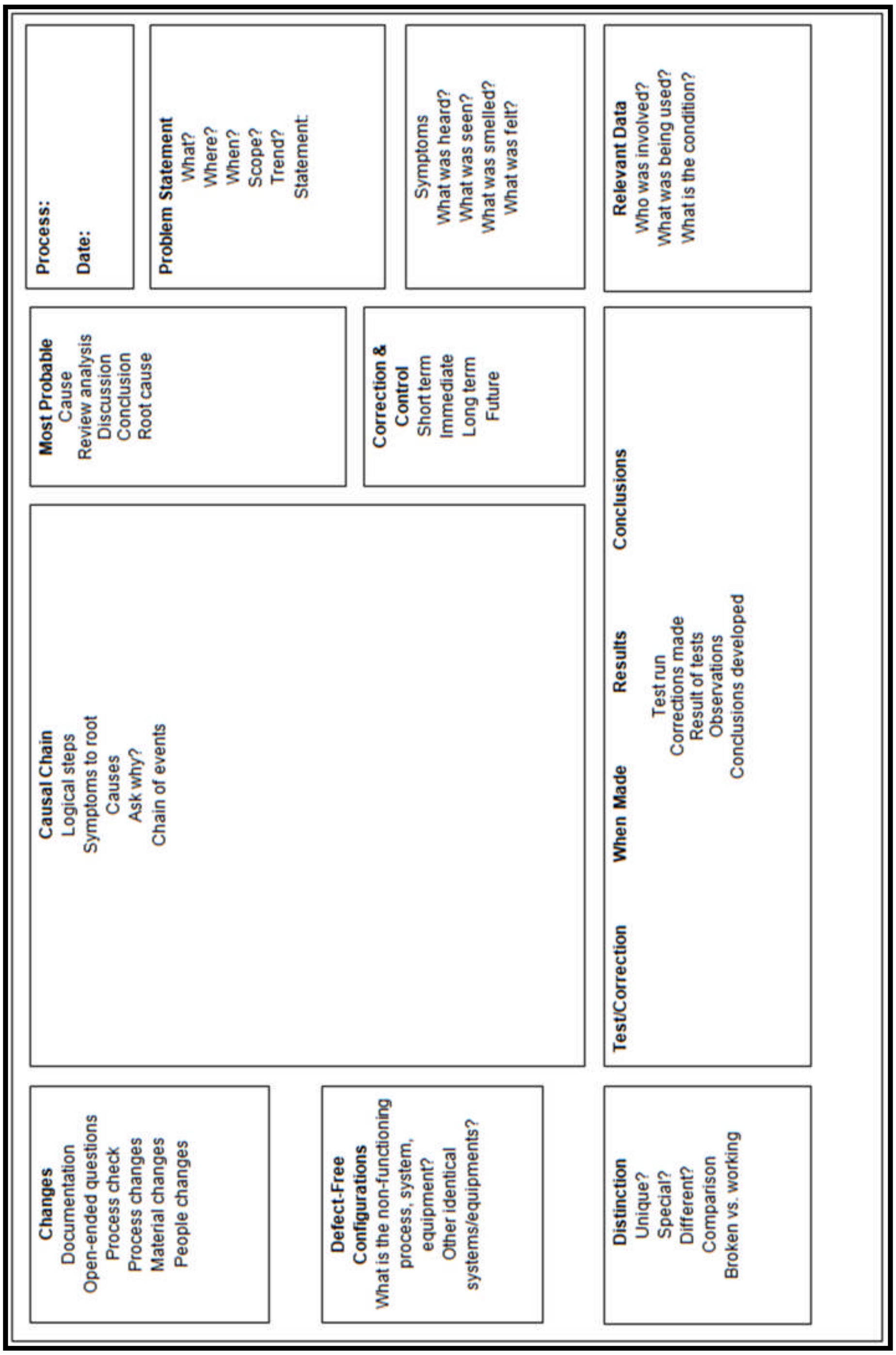
Appendix 1: The Template of 5 Whys



Appendix 2: Root Cause Analysis (RCA) Template

ISSUE				LIKELY ROOT CAUSE			POSSIBLE SOLUTIONS					
		Criticality						Risk			Measure of Success	
Description	Source	Level (High, Med, Low)	Rationale	Description	Likelihood (Low, Med, High)	Information/ Test to clarify	Description	Description	Likelihood	Mitigation	Test	Result

Appendix 3: The Template of Problem Analysis Flowchart (PAF)



Appendix 4: The Template of 8 Disciplines (8D)

Tracking Number:	Customer Number:	Response Due Date:

8-D is a quality management tool and is a vehicle for a cross-functional team to articulate thoughts and provides scientific determination to details of problems and provide solutions. Organizations can benefit from the 8-D approach by applying it to all areas in the company. The 8-D provides excellent guidelines allowing us to get to the root of a problem and ways to check that the solution actually works. Rather than healing the symptom, the illness is cured, thus, the same problem is unlikely to recur.

Step	0	1	2	3	4	5	6	7	8
Action	The Planning Stage	Establishing the Team	Problem Definition / Statement & Description	Developing Interim Containment Action	Identifying & Verifying Root Cause	Identifying Permanent Corrective Actions (PCA)	Implementing & Validating PCA	Preventing Recurrence	Recognizing Team Efforts

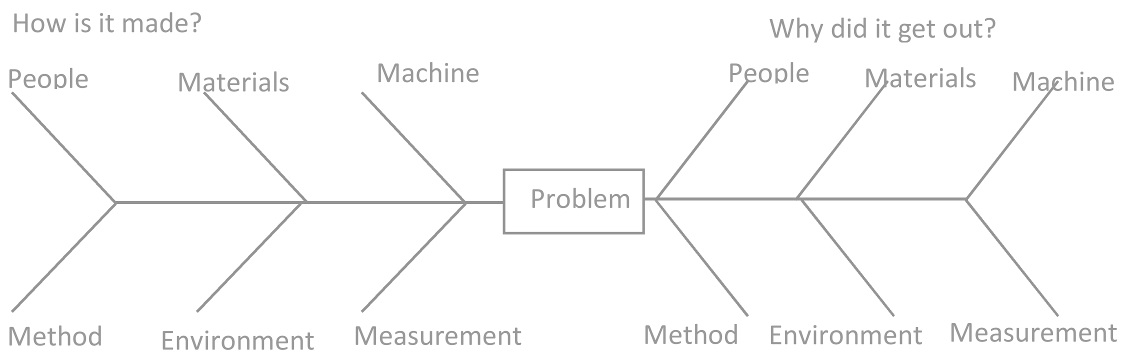
0	The Planning Stage: The 8-D method of problem solving is appropriate in "cause unknown" situations and is not the right tool if concerns center solely on decision-making or problem prevention. 8-D is especially useful as it results in not just a problem-solving process, but also a standard and a reporting format. Does this problem warrant/require an 8D? If so comment why and proceed.	Is an Emergency Response Action Needed? (If needed document actions in Action Item Table)
1	Establishing the Team: Establish a small group of people with the process/ product Knowledge, allocated time, authority and skill in the required technical disciplines to solve the problem and implement corrective actions.	Team Goals: Team Objectives:

Department	Name	Skills	Responsibility

2A	Problem Definition Provides the starting point for solving the problem or Non-conformance issue. Need to have "correct" problem description to identify causes. Need to use terms that are understood by all.	Sketch / Photo of Problem
	Part Number(s):	
	Customer(s):	
	List all of the data and documents that might help you to define the problem more exactly?	
	Action Plan to collect additional information:	
	Prepare Process Flow Diagram for problem use a separate sheet if needed	

2B	IS	IS NOT
Who	Who is affected by the problem? Who first observed the problem? To whom was the problem reported?	Who is not affected by the problem? Who did not find the problem?
What	What type of problem is it? What has the problem (part id, lots, etc)? What is happening with the process & with containment? Do we have physical evidence of the problem?	What does not have the problem? What could be happening but is not? What could be the problem but is not?
Why	Why is this a problem (degraded performance)? Is the process stable?	Why is it not a problem?
Where	Where was the problem observed? Where does the problem occur?	Where could the problem be located but is not? Where else could the problem be located but is not?
When	When was the problem first noticed? When has it been noticed since?	When could the problem have been noticed but was not?
How Much/ Many	Quantity of problem (ppm)? How much is the problem costing in dollars, people, & time?	How many could have the problem but don't? How big could the problem be but is not?
How Often	What is the trend (continuous, random, cyclical)? Has the problem occurred previously?	What could the trend be but is not?
2C	Problem Description (based on the information gathered so far, provide a concise problem description)	

3	Developing Interim Containment Actions Temporary actions to contain the problem and "fix" until permanent correction is in place - document actions in Action Item Table
4A	Identifying & Verifying Root Cause Analyze for "Root Cause" of the problem. Identify and verify the Escape Point
	Brainstorm the possible causes of the problem
4A	Cause and Effect Diagram



circle the most likely contributors (a maximum of three) from each side.

4B	5 Why Analysis

Ask – Why did this happen?

Ask – Why did this happen?

Ask – Why did this happen?

Ask – Why did this happen?

Ask – Why did this happen?

4C	Action Plan Based on the team's discussions. Begin to complete the Root Cause Action Plan to verify and validate the root causes and test the escape point. Document this on the Action Item Table

5	Identify Permanent Corrective Actions solutions that address and correct the root cause. Solutions determined to be the best of all the alternatives. Document and verify the Permanent Corrective Action (PCA) in the Action Item Table
6	Implementing & Validating the PCA Implement and validate to ensure that corrective action does "what it is supposed to do." Detect any undesirable side effects. Document this on the Action Item Table. Return to root cause analysis, if necessary
7	Preventing Recurrence determine what improvements in systems and processes would prevent problem from recurring. Ensure that corrective action remains in place and successful
7A	Address Similar Systems

Process / Item	Who Responsible	When

7B	Review the following documents / systems			
Document		Who Responsible	Completion Date	
			Planned	Actual
Management System Manual				
Manufacturing Work Instructions				
Inspection Work Instructions				
Process Flow Charts				
Process Control Plans				
Design FMEA				
Process FMEA				
Gages				
PPAP				
Engineering Change Approval				

8	Congratulate Your Team Use all forms of employee recognition and document as necessary Celebrate successful conclusion of the problem solving effort Formally disengage the team and return to normal duties

Was this problem solving exercise effective? Has it been verified with a follow-up?

Yes No	Signature / Title / Date	Findings

Action Item Table

Actions			Implement & Verify Actions					
Action #	Problem	Containment / Corrective Action	How Verified	Action	Who Responsible	Planned	Actual	Status

Appendix 5: Semi-structured Questionnaire

Semi Structured Questionnaire

Project Title:

Document Authors:

Academic Supervisor

Industrial Supervisor

INTERVIEWEE DETAILS

Name	
Position	
Briefly explain your position	
Years of Experience in current role	
Previous Role (s)	
Years of experience in previous role (s)	

1. LEARNING CYCLES

1.1 Do you use **learning cycles** as guidelines for continuous improvement? (Select One)

	Never used learning cycles as a continuous improvement
	Just decided to implement learning cycles as a continuous improvement
	Familiar about one of the learning cycles but never use as an informal way
	Applied loosely one of the learning cycles as a continuous improvement
	Applied one of the learning cycles as a continuous improvement
	Fully implementing learning cycles for continuous improvement

1.2 Which of the following **learning cycles** have you formally implemented as guide of continuous improvement in your company? How effective do you find them?

Learning Cycles	**Frequency**			**Effectiveness**		
	Never	Sometimes	Always	Not Effective	Somehow Effective	Very Effective
Plan-Do-Check-Act (PDCA)						
Look-Ask-Model-Discuss-Act (LAMDA)						
Six Sigma						
Design for Six Sigma						
Other:						
Other:						

2. PROBLEM SOLVING APPROACHES

2.1 Which of the following **approaches** have you formally implemented as a tool to solve problems in product design and development?

Approaches	Frequency			Effectiveness		
	Never	Sometimes	Always	Not Effective	Somehow Effective	Very Effective
Checklist						
Root Cause Analysis						
5 whys						
Problem Analysis Flow Chart						
8 Disciplines						
A3 report						
Other:						
Other:						

2.2 Which of the following **elements** must be considered as important information during problem solving in product and process design?

Elements	Descriptions	Importance		
		Not Important	Somehow Important	Important
Build Team	identify the team that should be involved			
Background	background information and historical data			
Current condition	represents the actual situation happened			
Future goal	present the company/team goal			
Containment	initial action until permanent correction is implemented			
Root cause analysis	investigate the root cause of the problem from current situation			
Countermeasures	measure the issue happened			
Generate possible solutions	analyse the solution and confirm the success			
Implementation plan	provide the future action & verify the effectiveness			
Prevent recurrence	modify and control the performance			
Follow-up Action	investigate any similar process that can prevent problem in future			
Other:				

3. METHODOLOGY

3.1 Which of the following are important to be considered during the process of problem solving?

Process of problem solving	**Frequency**			**Effectiveness**		
	Never	Sometimes	Always	Not important	Somehow important	Important
1. Identify the problem						
2. Understand the problem						
3. Visualise the problem using a template that easy to identify root cause of the problem						
4. Generate the solutions						
5. Apply the solutions						
6. Measure the success						
7. Present the generation of the solutions and measurements to brainstorm among peer.						
8. Implement the final solution that addressed the root cause.						
9. Present the implementation of the solutions for future reference						
10. Provide the process of learning cycles for continuous improvement						
11. Present the reflecting process from the lessons learnt to turn the experience into proper learning						
12. Create a useful knowledge using a simple template from above processes to be shared and communicated						
Other:						
Other:						

3.2 Give your opinions for the below statement.

"The process of solving a problem will create knowledge. The latter is needed to capture and share in a simple manner as a reference for effective decision making in the future"

Strongly Disagree	Disagree	Agree	Strongly Agree
( )	( )	( )	( )

3.3 Please rate how satisfied are you with the following practices in your company?

Knowledge	**Rate**			
	Very Poor	Fair	Good	Excellent
a) Knowledge creation from problem solving				
b) Knowledge capture using a template				
c) Knowledge sharing with simple manner				

Appendix 6: First Version of A3LAMDA Template

(Please Refer Appendix 6 at the Folder of 'Figures and Appendices')

Appendix 6: First Version of A3LAMDA Template

1. Team : Author: Date: Title: A3 Report No.:

Look, Ask → *Model, Discuss & Act* → *Reflection on Action*

2. Background *(Look)*

Product Type	
Product Name	
Product Code	
Software No.	
Printed Circuit Board No.	
Serial No. (S/N)	
Customer Spec.	

Product Picture

3. Current Condition *(Look& Ask)*

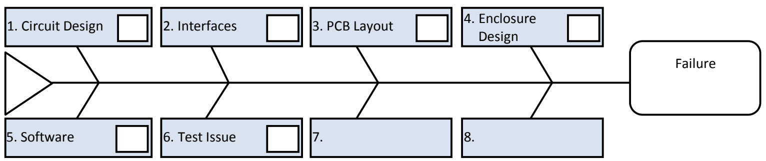
Test Request No.		Functional Status	
Test Type.		Functional Performance Class	
Other Information		Occurrence	

Not effect:

Effect of Failure:

Failure Test Diagram

4. Root Cause Analysis *(Ask)*



No.	Causes	Reason

5. Proposed Solutions *(Model-Discuss)*

No	Solutions	Confirmation			Type of Solutions	
		N/Eff	S/Eff	V/ Eff	Cont	Perm

BEFORE	PROPOSE
Design Ref. No.:	Design Ref. No.:

6. Implementation Plan *(Discuss-Act)*

No Sol.	Tasks	Actions to Implement Proposed Solutions	Responsibility & Duration

Result:

Result Test Diagram

7. Prevent Recurrence *(Act)*

8. Follow-up Action *(Act)*

a. What?
What is the knowledge?

Formulate the Solution OR Experience as Design Rule (DR)/Recommendation (Rec):

Design Rules (DR)	Design Issues: Circuit Design	PCB Layout	Interfaces	Software	Enclosure Design	Other
DR 1 Rec 1						
DR 2 Rec 2						
DR 3 Rec 3						
DR 4 Rec 4						

b. So What?
Where is the knowledge created?

c. Now What?
Where knowledge is needed?

DR / Red	Function	Activity

Appendix 7: Example of A3LAMDA Report for First Version

(Please Refer Appendix 7 at the Folder of 'Figures and Appendices')

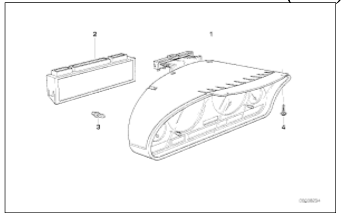
Appendix 7: Example of First Version of A3LAMDA Report

1. Team : AK, KS, & MS | Author: AK | Date: 22/10/2010 | Title: Radiated Emission (RE) Test | A3 Report No.: AK/RE/10/2010

Look, Ask | *Model, Discuss & Act* | *Reflection*

2. Background *(Look)*

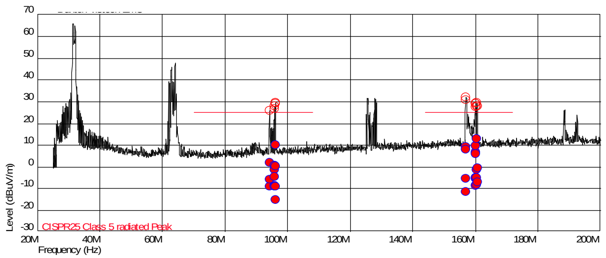
Product Type	Cluster
Product Name	Cluster Class D_01
Product Code	XX-002-NBD
Software No.	12-34-56
Serial No. (S/N)	XXXXX001-01
Printed Circuit Board No.	XXXXXNBDS01
Customer Spec.	XXX.01



3. Current Condition *(Look-Ask)*

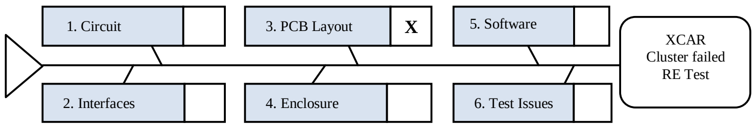
Test Request No.	TR.ER001XX	**Functional Status**	A
Test Type.	Radiated Emissions (RE)	**Functional Performance Class**	1
Other Information	No	**Occurrence**	1

Effect of Failure: The constant current drive circuit for the gauge illumination going into positive feedback and radiated at 31.4MHz.



4. Root Cause Analysis *(Ask)*

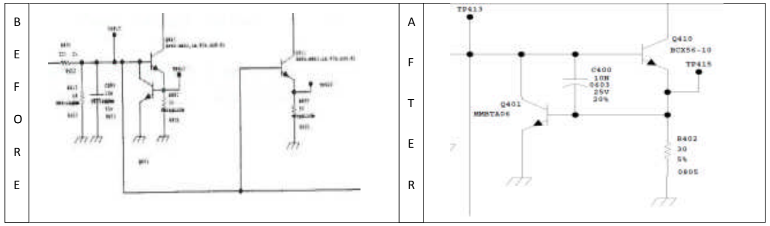
Any Diagnosis: - Putting the cluster in Daylight and Night time modes.



No.	Causes	Reason
3	Gauge illumination	-Daylight operating mode = OFF, Night time operating mode = ON.
		-Capacitor-X was incorrectly positioned in PCB layout.

5. Proposed Solutions *(Model-Discuss)*

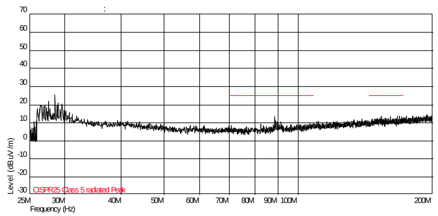
No	Solutions	Confirmation N/EFF	S/EFF	V/ EFF	Types of Solutions TMP	PERM
3	Put the capacitor-X close to the constant current drive circuit and between the base and collector of voltage clamping transistor.		x			x



6. Implementation Plan *(Discuss-Act)*

No.	Tasks	Actions to Implement Proposed Solutions	Responsibility & Duration
3.1	Redesign	-Put capacitor-X close to constant current driven circuit and between the base and collector of voltage clamping transistor.	Detail EMC Designer (1 Week)
3.2	Re-test	-The modified design for XCAR cluster performs the RE test.	EMC Test Eng. (2 weeks)

Result: The modified XCAR design cluster is Passed



7. Prevent Recurrence *(Act)*

-**Awareness**: the constant current drive circuit will possibly go into positive feedbacks and so a capacitor -X is required to slow the response of the voltage clamping transistor to the PWM signal input on the base.

-**Standardisation:** On any constant current drive circuit it should package protect for a capacitor-X close the clamping to stop the positive feedback should be captured in the schematic and the layout document.

8. Follow-Up Action *(Act)*

- **Continuous improvement:** Simulation of the circuit to analyse the phase and gain margin to ensure the circuit is stable.

a. What?

What is the knowledge?

- Formulate the Solution OR Experience as Design Rule (DR)/Recommendation (Rec):

Design Rules (DR)	Design Issues: Circuit Design	PCB Layout	interfaces	Software	Enclosure Design	Other
DR 1 / Rec 1 Placing the capacitor-X correctly in PCB layout will prevent radiated emission.	X	X				
DR 2 / Rec 2 Implement the constant current drive circuit to ensure the illumination is stable.		X				
DR 3 / Rec 3						

b. So What?

Where the knowledge is created?

- The placing of the capacitor-X close the clamping transistor to stop the positive feedback should be captured in the schematic and the layout document.

c. Now What?

Where the knowledge is needed?

DR / Red	Function	Activity
DR 1	Elec. Eng.	Schematic Design and Approval
Rec 2	Elec. Eng.	Create Electrical Bill Of Material

Appendix 8: Second Version of A3LAMDA Template

(Please Refer Appendix 8 at the Folder of 'Figures and Appendices')

Appendix 8: Second Version of A3LAMDA Template

1. Team : Author: Date: Title: A3 Report No.:

Look, Ask → *Model, Discuss & Act* → *Reflection on Action*

2. Background *(Look)*

Product Type	
Product Name	
Product Code	
Software No.	
Printed Circuit Board No.	
Serial No. (S/N)	
Customer Spec.	

Product Picture

3. Current Condition *(Look& Ask)*

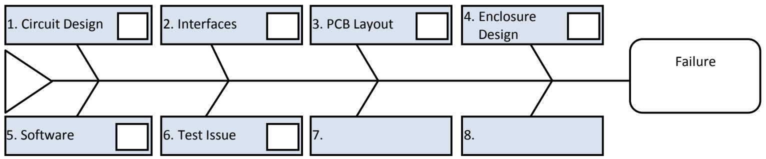
Test Request No.		Functional Status	
Test Type.		Functional Performance Class	
Other Information		Occurrence	

Not effect:

Effect of Failure:

Failure Test Diagram

4. Root Cause Analysis *(Ask)*



No.	Causes	Reason

5. Proposed Solutions *(Model-Discuss)*

No	Solutions	Confirmation			Type of Solutions	
		N/Eff	S/Eff	V/ Eff	Cont	Perm

BEFORE	PROPOSE
Design Ref. No.:	Design Ref. No.:

6. Implementation Plan *(Discuss-Act)*

No Sol.	Tasks	Actions to Implement Proposed Solutions	Responsibility & Duration

Result:

Result Test Diagram

7. Prevent Recurrence and Follow-up Action *(Act)*

Questions for Prevent Recurrence	Y	N	Descriptions & Actions to Prevent Recurrence
1. Does the solution impact other EMC tests?			
2. Any consequences of possible solution cause to other products and/or processes?			
3. Is the solution the best possible options? If yes, why?			

a. What?
What is the knowledge?

Formulate the Solution OR Experience as Design Rule (DR)/Recommendation (Rec):

Design Rules (DR)	Design Issues					
	Circuit Design	PCB Layout	Interfaces	Software	Enclosure Design	Other
DR 1 Rec 1						
DR 2 Rec 2						
DR 3 Rec 3						
DR 4 Rec 4						

b. So What?
Where is the knowledge needed?

DR / Red	Function	Activity

c. Now What?
Has the knwoledge been standardised?

Appendix 9: Example of A3LAMDA Report 1 for Second Version

(Please Refer Appendix 9 at the Folder of 'Figures and Appendices')

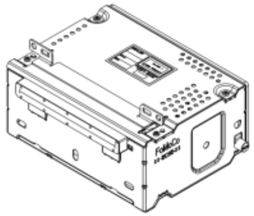
Appendix 9: Example 1 for Second Version of A3LAMDA Report

1. Team : PA, IP, MS, CC and RR | Author: MS | Date: 01/ 12/ 2011 | Title: LXC+ Class D Rod Antenna RE failure | A3 Report No.: MS/RE/12/2011

Look, Ask — *Model, Discuss & Act* — *Reflection*

2. Background *(Look)*

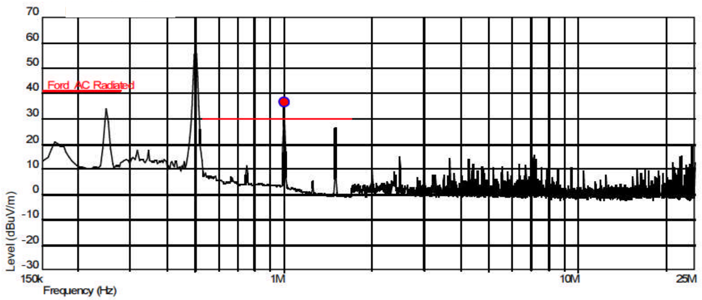
Product Type	Audio
Product Name	CXXX LXC+ Class D DAB
Product Code	VXXXX-XCXX-DC
Software No.	BMXX-XXXX-NCXYZ
Printed Circuit Board No.	XYZ
Serial No. (S/N)	Sample 1: ZXYZ Sample 2: ZXYZ
Customer Spec.	XX-XYZAC



3. Current Condition *(Look)*

Test Request No.	EL10.WXYZ	**Functional Status**	N/A
Test Type.	Radiated Emission (RE130)	**Functional Performance Class**	N/A
Other Information	Same failure for MP3, FM, AM, DAB	**Occurrence**	1

Effect of Failure: ➢ Rod antenna is failed the radiated emissions.

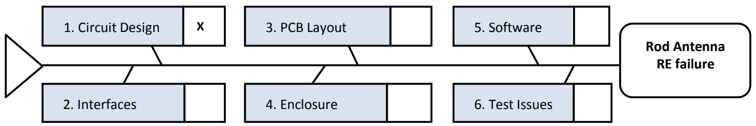


Peak Result 0

Frequency(Hz)	Level(dBuV/m)	Limit(dBuV/m)	Margin(dBuV/m)	Detector	RBW(Hz)
1.002 M	36.47	30.00	6.47	PEAK CISPR	9.0 k

4. Root Cause Analysis *(Ask)*

Any Diagnosis:



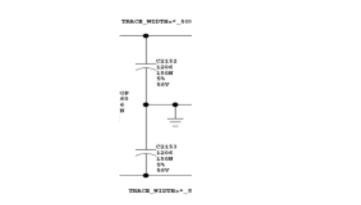
Other:________________________

No.	Causes	Reason
1.1	Class-D Amp (Confirmed by freq change)	
1.2	Could be on power wires	
1.3	Could be speaker cables	

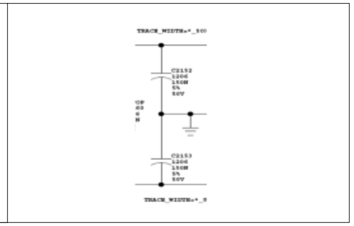
5. Proposed Solutions *(Model-Discuss)*

No	Solutions	Confirmation			Types of Solutions	
		N/EFF	S/EFF	V/ EFF	TMP	PERM
1.1	Spread spectrum on clock	X				X
1.2	Changes to power supply filter to Class-D Amplifier	X				X
1.3	Change to Class-D output filters. Cx, Cy to 1uF		X			X

B E F O R E



A F T E R

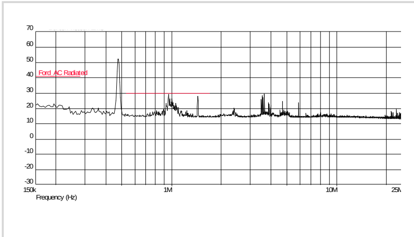


6. Implementation Plan *(Discuss-Act)*

No Sol.	Tasks	Actions to Implement Proposed Solutions	Responsibility & Duration
1.3.1	Update design	Change schematic, (Bill of Materials) BOM	CC
1.3.2	Verify changes	Development testing	MS
1.3.3	Formal Testing	MoC, Raise new TR, update samples	RR

Result:

➢ The diagram shows the comparison results where the RE for rod antenna is under limit = 25MHz.



7. Prevent Recurrence & Follow-up Action *(Act)*

Questions for Prevent Recurrence	Y	N	Descriptions & Actions to Prevent Recurrence
1. Does the solution impact other EMC tests?	x		MoC Check on Audio output quality/output power Retested as TR.ELxx.0xyz
2. Any consequences of possible solution cause to other products and/or processes?		X	
3. Is the solution the best possible option? If Yes, why?	X		Simple change, Zero on-cost, low risk

Reflection

a. What?

What is the knowledge?

- Formulate the Solution OR Experience as Design Rule (DR)/Recommendation (Rec):

Design Rules (DR)	Design Issues: Circuit Design	PCB Layout	Interfaces	Software	Enclosure Design	Other
DR 1 / Rec 1 Class- D Output Low Pass filter should have low enough cut-off to reduce amplitude of switching frequency and harmonics.	X					
DR 2 / Rec 2 Testing needs to ensure that all outputs fully exercised.						X
DR 3 / Rec 3						

b. So What?

- Where is the knowledge needed?

DR / Red	Function	Activity
Rec1	El Engineering	Schematic Design and approval (41)
Rec 2	Hardware PA	Develop Hardware Test Plan (62)

c. Now What?

Has the solution been standardised? Explain.	Y	N	
	X	X	Values used in similar circuit. Needs to be fed into previously tested product.

Appendix 10: Example of A3LAMDA Report 2 for Second Version

(Please Refer Appendix 10 at the Folder of ‘Figures and Appendices’)

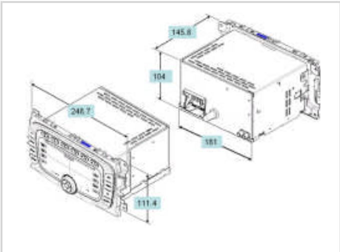
Appendix 10: Example 2 for Second Version of A3LAMDA Report

1. Team : MS, MB, MA and IP | Author: MS | Date: 15/06/2011 | Title: CDxxx MCA RI 114 FM SINAD | A3 Report No.: MS/RI/06/2011

Look, Ask | *Model, Discuss & Act* | *Reflection*

2. Background *(Look)*

Product Type	Radio
Product Name	Client F CDxxx MCA Radio xxxx DAB “Square Bezel”
Product Code	Bx4z-xxCxyz-DA
Software No.	xx-yy-zz
Printed Circuit Board No.	WXYZ
Serial No. (S/N)	#1:V0000XY #2:V0000YZ
Customer Spec.	XYZ.00123



3. Current Condition *(Look)*

Test Request No.	TR.ELXX.001	**Functional Status**	I/II
Test Type.	Radiated Immunity (RI)	**Functional Performance Class**	1/2
Other Information	Affected for SONY & Premium variants	**Occurrence**	

Effect of Failure: ➢ SINAD failure on the CDxxx XXXX KGA radio in Radiated Immunity, RI114 testing.

Sample 1

Observations
Band 5B, FM mode.

Orientation Y
Vertical
SINAD failure at 1720MHz, 45V/m PM.
Horizontal
SINAD failure at 1780MHz, 44V/m PM.
SINAD failure at 1800MHz, 34V/m PM.

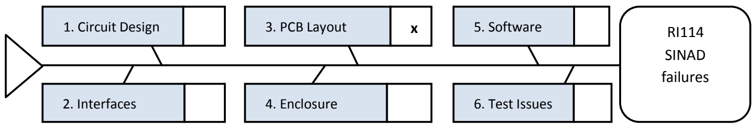
Orientation Z
Vertical
SINAD failure at 1800MHz, 40V/m PM.
Horizontal
SINAD failure at 1780MHz, 34V/m PM.
SINAD failure at 1800MHz, 28V/m PM.
SINAD failure at 1820MHz, 39V/m PM.

Observations
Band 5B, FM mode.
Orientation X
Vertical
SINAD failure at 1760MHz, 29V/m PM.
SINAD failure at 1780MHz, 24V/m PM.
SINAD failure at 1800MHz, 25V/m PM.
SINAD failure at 1820MHz, 33V/m PM.
SINAD failure at 1840MHz, 36V/m PM.
SINAD failure at 1860MHz, 45V/m PM.
SINAD failure at 1960MHz, 45V/m PM.
SINAD failure at 1980MHz, 45V/m PM.
SINAD failure at 2000MHz, 41V/m PM.
Orientation Z
Vertical
SINAD failure at 1700MHz, 44V/m PM.
SINAD failure at 1720MHz, 36V/m PM.
SINAD failure at 1740MHz, 36V/m PM.
SINAD failure at 1760MHz, 43V/m PM.
SINAD failure at 1780MHz, 32V/m PM.
SINAD failure at 1800MHz, 32V/m PM.
SINAD failure at 1820MHz, 40V/m PM.
SINAD failure at 1840MHz, 40V/m PM.
SINAD failure at 1860MHz, 45V/m PM.
Horizontal
SINAD failure at 1780MHz, 31V/m PM.
SINAD failure at 1800MHz, 35V/m PM.

Sample 2

4. Root Cause Analysis *(Ask)*

Any Diagnosis: ➢ Experimental tests only. Testing limited to band 5B where main issues have been seen.

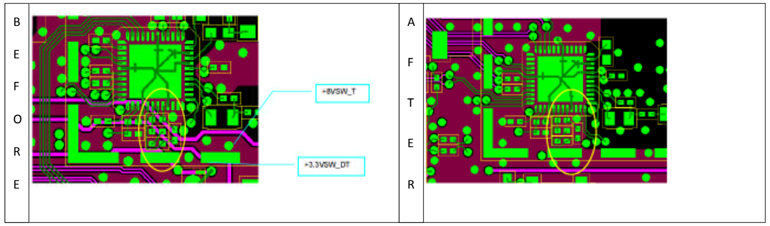


Other:________________________

No.	Causes	Reason
3.1	Tuner Layout	- The plane is broken by two power supply tracks (+8xxx_T and +3.3xxx_DT).
		-The +3.3xxx_DT line is open at both ends.The length of the 3.3xxx track is approx 3in at 1.8GHz.
		- Data Tuner +3.3xxx_DT is not fitted.
		- Length of the track.

5. Proposed Solutions *(Model-Discuss)*

No	Solutions	Confirmation			Types of Solutions	
		N/EFF	S/EFF	V/ EFF	TMP	PERM
3.1.1	Bypassing diplexer	X			X	
3.1.2	Tuner shield fit in properly		X			X
3.1.3	Cable layout for test		X		X	
3.1.4	To fit the Cxx and Cyy to reduce the impedance on the length of track.			X	X	

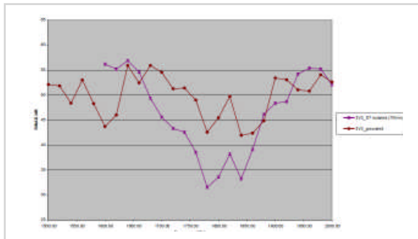


6. Implementation Plan *(Discuss-Act)*

No Sol.	Tasks	Actions to Implement Proposed Solutions	Responsibility & Duration
3.4.1	Redesign	Fitting the 0ohm links both Cxx and Cyy	Plant-2 weeks
3.4.2	Re-test	The test is repeated and performance is tobe confirmed.	PA Eng and EMC Test Eng-1 week

Result:

➢ The modified unit seemed to show less degradation in the 1700-1900MHz frequency range.



7. Prevent Recurrence & Follow-up Action *(Act)*

Questions for Prevent Recurrence	Y	N	Descriptions & Actions to Prevent Recurrence
1. Does the solution impact other EMC tests?	x		RI112 was performed to ensure FM performance is maintained. RE310 was performed to ensure hardware change does not affect emissions.
2. Any consequences of possible solution cause to other products and/or processes?		x	

8. What?

What is the knowledge?

- Formulate the Solution OR Experience as Design Rule (DR)/Recommendation (Rec):

Design Rules (DR)	Design Issues: Circuit Design	PCB Layout	Interfaces	Software	Enclosure Design	Other
DR 1 Rec 1 The layout eng should ensure that the tracks does not run under sensitive circuit.		X				
DR 2 Rec 2 The shecmatic should identify the sensitive parts of circuit.	X					
DR 3 Rec 3 Need to review the impact of the depopulating and components						X

9. So What?

Where is the knowledge needed?

DR / Red	Function	Activity
Rec 1	Electrical Eng	
Rec 2	Electrical Eng	
Rec 3	Electrical Eng	

9. Now What?

	Y	N	
1. Is the solution the best possible option? If yes, Why?		X	
2. Has the solution been standardised?		X	

Appendix 11: Interface of the A3LAMDA Template Microsoft Developer

(Please Refer Appendix 11 at the Folder of 'Figures and Appendices')

Appendix 11: Interface of the A3LAMDA Template in Microsoft Developer

1. TEAM:	Author:	Date: Click here to enter a date.	Title:	A3 Report No.:

Look-Ask — *Model-Discuss-Act* — *Reflection*

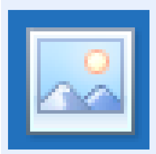
Failure Documentation Report

2. BACKGROUND

Product Type	Select
Product Name	
Product Code	
Software No.	
Printed Circuit Board No.	
Serial No. (S/N)	
Customer Spec.	Select
Other Information:	

3. CURRENT CONDITION

Test Request No.		Functional Status	Select
Test Type.	Select	Functional Performance Class	Select
Test Report No.		Occurrence	Select
Other Information			
Description of failure:			



4. ROOT CAUSE ANALYSIS

Any Diagnosis:

1. Circuit Design: ☒
3. PCB Layout: ☐
5. Software: ☐
2. Interfaces: ☐
4. Enclosure: ☐
6. Other: ☐

Defect:

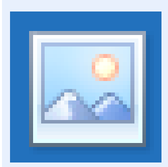
No.	Causes	Reason

5. PROPOSED SOLUTIONS

Previous A3LAMDA Reports

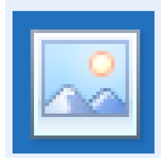
No.	Proposed Solutions	Effectiveness: Not	S/how	Very	Types Solution: Cont	Perm
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐
		☐	☐	☐	☐	☐

BEFORE



Reference No:

AFTER



Reference No:

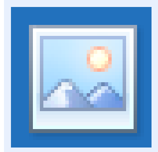
6. IMPLEMENTATION PLAN

No Sol.	Tasks	Actions to Implement Proposed Solutions	Key Roles & Duration

Results Details

Pass : ☐

Fail : ☐



7. PREVENT RECURRENCE

Questions for Prevent Recurrence	Y	N	Descriptions & Actions to Prevent Recurrence
1. Does the solution impact other EMC tests?	☐	☐	
2. Any consequences of possible solution cause to other products and/or processes?	☐	☐	

8. WHAT? *What is the knowledge*

No.	Lesson Learned
1	
2	
3	
4	
5	

9. So What? *How this knowledge can be applied?*

Design Rules (DR)/Recommendation (Rec)	Design Issues: Circuit Design	PCB Layout	Interfaces	Software	Enclosure Design	Other
DR 1☐ Rec 1☐	☐	☐	☐	☐	☐	☐
DR 2☐ Rec 2☐	☐	☐	☐	☐	☐	☐
DR 3☐ Rec 3☐	☐	☐	☐	☐	☐	☐
DR 4☐ Rec 4☐	☐	☐	☐	☐	☐	☐

10. Now What? *Where the knowledge is needed?* Product Development Process Chart

DR/Rec	Function	Activity
Select	Select	Select
Select	Select	Select
Select	Select	Select
Select	Select	Select
Select	Select	Select

Appendix 12: A3LAMDA Report 1

(Please Refer Appendix 12 at the Folder of 'Figures and Appendices')

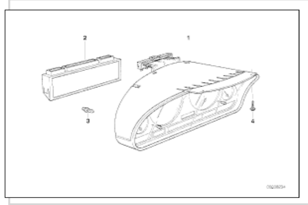
Appendix 12: A3LAMDA Report 1

1. Team : KG and AK | Author: AK | Date: 02/03/2012 | Title: X-cluster fail xy/MRxx Measurement of Magnetic Radiated Emissions | A3 Report No.: AK/RE/03/2012

Look, Ask → *Model. Discuss & Act* → *Reflection*

2. Background

Product Type	cluster
Product Name	X-cluster Hx and Lx
Product Code	xxxx.01.xyz
Software No.	X01
PCB No.	Pw.001x
Serial No. (S/N)	xx.001.21
Customer Spec.	x-01-8xx/--K
Other Information:	

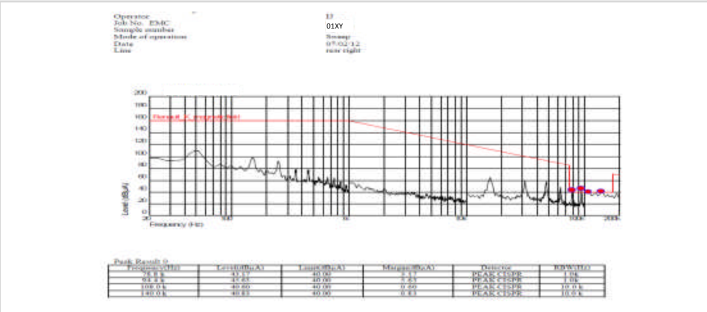


3. Current Condition

Test Request No.	TR.xy12.01	Functional Status	
Test report No.	Radiated Emission (RE)	Functional Performance Class	
Test Type.	Validation Emissions	Occurrence	

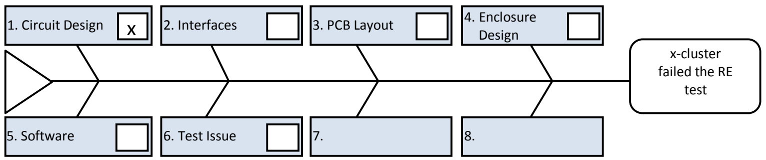
Other Information: The loop antenna is positioned on the rear RHS of the cluster and the emissions at 78.8kHz and 94.4kHz fail the limit line.

Description of Failure:



4. Root Cause Analysis

Any Diagnosis:

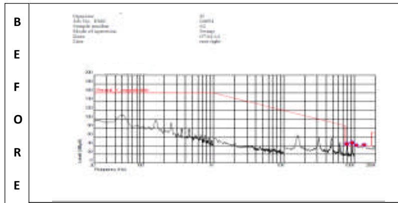


No.	Causes	Reason
1.1	Speaker	magnetic coil of speaker. (it's not the speaker as this is not driven)
1.2	Telltales	Current in tracks is at least 12mA.
1.3	Stepper Motors	Current in tracks at least 20mA.
1.4	Illumination	20mA in each LED branch of 11 branches.

5. Proposed Solutions

No	Solutions	Confirmation N/Eff	S/Eff	V/ Eff	Type of Solutions Cont	Perm
1.2	The x-spec is less than 40dBuA/m whereas the G spec requires 60dBuA/m.	x			x	
1.3	The mode of operation change to COMFORT mode where the tell tales and motors are not driven		x			x

BEFORE



Design Ref. No.:

PROPOSE

After Modification

Design /schematic Picture

Design Ref. No.:

6. Implementation Plan

No.	Tasks	Actions to Implement Proposed Solutions	Responsibility & Duration
1	Re-test	Change the mode of the cluster during the test.	EMC Tester

Result:

Result Test Diagram

7. Prevent Recurrence & Follow-up Action

Questions for Prevent Recurrence	Y	N	Descriptions & Actions to Prevent Recurrence
1. Does the solution impact other EMC tests?		x	
2. Any consequences of possible solution cause to other products and/or processes?	x		The limit line from the G specification should be used and the mode of testing should be COMFORT mode for EQ.MR xy

8. What?- What is the knowledge?

Lessons Learned
1. The lesson to be learnt is that during the pre-DV the test was NOT done correctly as only the front face was tested. If we had this information earlier then we would have discussed this with Renault before validation started and we would have negotiated tesing to the G spec requirements.

9. So What? How can the knowledge be applied?

Type of Knolwedge : Design Rule (DR)/ Recomendation (Rec)	Design Issues: Circuit Design	PCB Layout	Interfaces	Software	Enclosure Design	Other
DR 1 Rec 1 The pre-DV test must be correctly and fully performed before validation.	x					
DR 2 Rec 2						
DR 3 Rec 3						

10. Now What? Where is knowledge needed?

DR / Red	Function	Activity
Rec 1	Product Assurance and Software Validation	Execute Test Plan (74)
	Electrical Engineering	Develop Verification Test Plans (49)

Appendix 13: A3LAMDA Report 2

(Please Refer Appendix 13 at the Folder of 'Figures and Appendices')

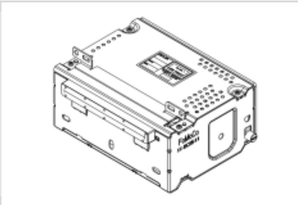
Appendix 13: A3LAMDA Report 2

1. **Team** : MS | Author: MS | Date: 02/05/2012 | Title: L538 AHU USB mode emissions | A3 Report No.: MS/RE/05/2012

Look, Ask | *Model. Discuss & Act* | *Reflection*

2. Background

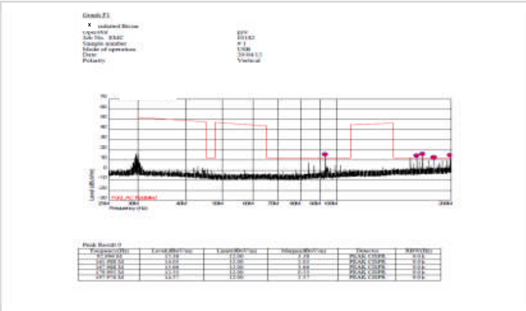
Product Type	Audio
Product Name	LXXX AHU
Product Code	DHxy-18x001-BC
Software No.	0x.1e.00
PCB No.	PWB wxyz01
Serial No. (S/N)	Z00001, Z00002
Customer Spec.	ES-001K
Other Information:	



3. Current Condition

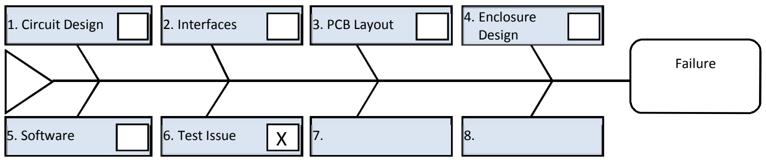
Test Request No.	TR.EL12.0001	Functional Status	N/A
Test report No.	TR.EL12.0002	Functional Performance Class	N/A
Test Type.	Radiated Emission (RE)	Occurrence	All
Other Information			

Description of Failure: Emissions exceede in USB mode in FM and VHF bands and at 201MHz



4. Root Cause Analysis

Any Diagnosis:

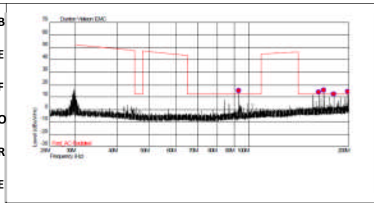


No.	Causes	Reason
6.1	Circuit design/layout	Unlikely, as changes mode in Parrott module software and hardware not expected to affect USB.
6.2	Test set-up	Checks made that same load filter used on USB memory stick. New back-back connector used for USB cable. Connector has poor shield continuity. Other test kit the same.
6.3	Test set-up - USB box laid on ground plane rather than on insulator	Gives different coupling between stick and GND plane.

5. Proposed Solutions

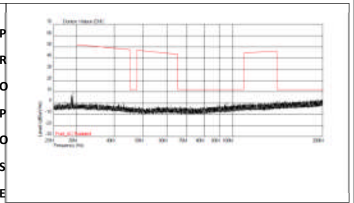
No	Solutions	Confirmation N/Eff	Confirmation S/Eff	Confirmation V/ Eff	Type of Solutions Cont	Type of Solutions Perm
6.2	Improve shield continuity on USB back-back connector (Copper Tape)			X		X

BEFORE



Design Ref. No.:

PROPOSE



Design Ref. No.:

6. Implementation Plan

No.	Tasks	Actions to Implement Proposed Solutions	Responsibility & Duration
1	1	Re-test with corrected connector	Test lab 1 day

Result:

Result Test Diagram

7. Prevent Recurrence & Follow-up Action

Questions for Prevent Recurrence	Y	N	Descriptions & Actions to Prevent Recurrence
1. Does the solution impact other EMC tests?		X	
2. Any consequences of possible solution cause to other products and/or processes?		X	

8. What? What is the knowledge?

Lessons Learned
1. Support equipment is key to measured results.
2. Problem introduced because support kit changed from first test phase.
3. Support kit should be validated before use (unfortunately, in this case would need to have done an RE test to check the support kit !)

9. So What? How can the knowledge be applied?

Type of Knolwedge : Design Rule (DR)/ Recomendation (Rec)	Circuit Design	PCB Layout	Interfaces	Software	Enclosure Design	Other
DR 1 Rec 1 Check that support kit the same before testing, or re-validate any new/changed kit						x
DR 2 Rec 2						
DR 3 Rec 3						

10. Now What? Where is the knowledge needed?

DR / Red	Function	Activity
Rec 1	Product Assurance	Build/supply support Kit

Appendix 14: A3LAMDA Report 3

(Please Refer Appendix 14 at the Folder of 'Figures and Appendices')

Appendix 14: A3LAMDA Report 3

1. Team : MS | Author: MS | Date: 23/04/2012 | Title: India BXX radio Band 5A Radiated Immunity issues. | A3 Report No.: MS/RI/04/2012

Look, Ask | *Model. Discuss & Act* | *Reflection*

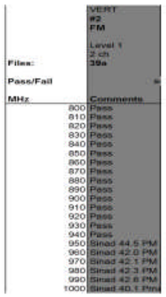
2. Background

Product Type	Audio
Product Name	BXX AHU
Product Code	AS01-1XXXX-AC
Software No.	3.XX
PCB No.	PWB XXXX
Serial No. (S/N)	AKR00011110 (sample #2 only)
Customer Spec.	ES-XWXY-1xx-AC
Other Information:	

3. Current Condition

Test Request No.	TR.EL12.0X	Functional Status	I
Test report No.	TR.EL12.0X	Functional Performance Class	A
Test Type.	Radiated Immunity (RI)	Occurrence	1
Other Information			

Description of Failure: BXX radio Band 5A failed the Radiated Immunity (RI) test

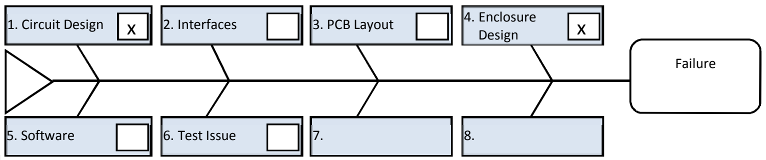


Files:	VERT #2 FM Level 1 2 ch 39a
Pass/Fail	
MHz	Comments
800	Pass
810	Pass
820	Pass
830	Pass
840	Pass
850	Pass
860	Pass
870	Pass
880	Pass
890	Pass
900	Pass
910	Pass
920	Pass
930	Pass
940	Pass
950	Sinad 44.5 PM
960	Sinad 42.0 PM
970	Sinad 42.1 PM
980	Sinad 42.3 PM
990	Sinad 42.6 PM
1000	Sinad 40.1 Pm

SINAD (Audio degradation seen for one sample only (#2) in band 5A, 950-1000MHz. Issue seen in FM only.

4. Root Cause Analysis

Any Diagnosis:

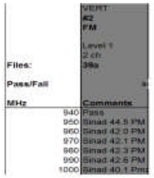


No.	Causes	Reason
1.1	Tuner circuit vulnerable to RI	Changes from previous design to include leaded components may have increased some sensitive loop areas.
4.1	Poor shielding for thissample	Checked screw connections on chassis.
4.2	Poor grounding for antenna cable	Checked screw mounting antenna cable to chassis - thread was poor and not possible to tighten.

5. Proposed Solutions

No	Solutions	Confirmation			Type of Solutions	
		N/Eff	S/Eff	V/ Eff	Cont	Perm
1.1	Fit new screw to ensure design intent contact between antenna screen and chassis		x		x	

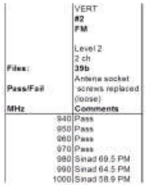
B E F O R E



Files:	VERT #2 FM Level 1 2 ch 39a
Pass/Fail	
MHz	Comments
940	Pass
950	Sinad 44.5 PM
960	Sinad 42.0 PM
970	Sinad 42.1 PM
980	Sinad 42.3 PM
990	Sinad 42.6 PM
1000	Sinad 40.1 Pm

Design Ref. No.:

A F T E R



Files:	VERT #2 FM Level 2 2 ch 39b
Pass/Fail	Antena socket screws replaced (loose)
MHz	Comments
940	Pass
950	Pass
960	Pass
970	Pass
980	Sinad 69.5 PM
990	Sinad 64.5 PM
1000	Sinad 58.9 PM

Pass against 50V/m Level 1 threshold.

Design Ref. No.:

6. Implementation Plan

No.	Tasks	Actions to Implement Proposed Solutions	Responsibility & Duration
1		Re-test with tight screw	Test labs 0.5 day
2		Feedback to design and plan	EMC apps 0.5

Result:

Result Test Diagram

7. Prevent Recurrence & Follow-up Action

Questions for Prevent Recurrence	Y	N	Descriptions & Actions to Prevent Recurrence
1. Does the solution impact other EMC tests?		x	
2. Any consequences of possible solution cause to other products and/or processes?	x		Always ensure that correctly built units submitted for test

8. What? What is the knowledge?

Lessons Learned
1. Poor grounding at antenna connector made unit more vulnerable to Radiated Immunity.
2. Process for supplying units for test needs to ensure quality of build etc.

9. So What? How can the knowledge be applied?

Type of Knolwedge : Design Rule (DR)/ Recomendation (Rec)	Circuit Design	PCB Layout	Interfaces	Software	Enclosure Design	Other
DR 1 Rec 1 All cable shield should have good, preferably 360 degree connection to chassis					x	
DR 2 Rec 2 Pre-test check -list to ensure checks that all screws etc. tightened to correct torque etc.						x
DR 3 Rec 3						

10. Now What? Where is the knowledge needed?

DR / Red	Function	Activity
Rec 1	Mechanical/ Electrical Engineering	Mechanical/Electrical design
Rec 2	Product Assurance and Software Validation	Execute Test Plan