CRANFIELD UNIVERSITY

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Integrating Failure Documentation with A3 Template to Improve Product Design Quality

School of Applied Science

MSc by Research Thesis

Academic Year: 2010-2012

Academic Supervisors:

Dr. Ahmed Al-Ashaab

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ABSTRACT

Design quality always has great impact on the competitive attribution of companies. Knowledge Management has become an important process which could help companies to accumulate the knowledge created in the past, and use it to solve the current problem and for future use. Failure Mode and Effect Analysis (FMEA) has been widely implemented as a technique for identifying potential problems, whilst A3 Thinking, has been developed by Toyota as a tool to help solve problems. However, no research exists regarding integrating these strategies for the purposes of knowledge creation, capturing and provision.

This research focuses on integrating an A3 Thinking Template and FMEA-based Failure Documentation which will be used to document the problem, solve the problem, allowing knowledge creation, capturing and provision. The objectives are to: (1) Synthesise the good practices of using FMEA and A3 thinking through a literature review; (2) Analyse the role and capability of FMEA and A3 thinking in capturing and communicating knowledge to support the generation of an improved design solution; (3) Design an integration between FMEA-based Failure Documentation and the A3 Thinking template for problem solving during the design stage to support knowledge visualisation and capturing in a dynamic manner; Then develop a checklist to present the knowledge captured; (4) Validate the integration via case study on product development process in collaborating company.

The proposed integration of FMEA-based Failure Documentation and A3 Thinking template has 3 stages. Firstly, problems will be documented into FMEA-based Failure Documentation template. Secondly, the A3 Thinking template with its procedure will enable users to follow the instructions to find out the solution and correct the problem.

And the solution and experience in problem solving, which is the knowledge, will be generated in A3 report to be provided to users for avoiding problem recurrence in future.

Key words: Design quality, knowledge management, problem solving, integration, visualisation, creation, capturing and provision.

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1. Introduction

The importance of design quality is emphasised today by increasing competitiveness in the global marketplace. Design quality has great impact on the competitiveness of a product in terms of the cost of fixing, loss of time, or loss of reputation caused by design errors (Emil and Steve, 1993). It is necessary for product designers to gain a high level of specific knowledge and experience as design decisions need to be made with intensive knowledge and interaction between different parameters. Traditionally, new product design mostly depends on the individual expertise of product designers. But a shortage of these experienced designers always occurs when they deal with new product development to satisfy the growing demand in the market.

In recent years, one way to improve the product design quality has been to utilize Failure Mode and Effect Analysis (FMEA), as a proven technique to support designers to identify the potential problems in order to avoid them. FMEA has been put into widespread use, and brought great benefits to its users. Following the applications of FMEA has proved an effective method of ensuring the quality of design (Onodera, 1997). As a systematic, risk preventive method, FMEA is used to reduce or even prevent the known or potential quality risks by identifying all the possible failure modes, evaluating their effects, occurrences and detection, finding the causes of the failure and proposing recommended actions to eliminate the risks before they occur. However, FMEA does not provide a detailed method which could help the users generate solutions to solve the problem. The FMEA template does not have enough space to allow the users to present the important information they gain from the problem solving activities, which is knowledge could be shared with others.

A3 Thinking, an approved successful approach from Toyota, has been used as a key tactic in sharing a deeper method of thinking which provides valuable information in a compact manner during problem solving activities. A3 Thinking template has its own constraints (A3 paper size, hence the name) and structure (specific categories, ordered in steps, adding up to a "story"), which can be effectively used to solve problems (Shook, 2009). An A3 report with all the important information related to the solved problem, will logically and visually present the experience or knowledge to the readers, which will contribute to knowledge sharing.

The challenge is to establish a method that could link FMEA-based Failure Documentation and A3 thinking in order to dynamically capture the knowledge during problem solving activities, then provide it to designers to help avoid the recurrence of same or similar failures and unexpected changes in the design stage, to help the company provide high quality products, and achieve cost saving.

The approach taken to develop the work presented in this thesis is action research with a 1st tier automotive supplier. One of the main challenges of the new product development of electrical sub-assembly in the company is the consideration of Electromagnetic Compatibility (EMC) requirements. Electromagnetic compatibility is "The ability of a device, unit of equipment or a system to function satisfactorily in its electromagnetic environment (Immunity aspect) without introducing intolerable electromagnetic disturbances to anything in that environment (Emission aspect)" (Richard, 1996). Nowadays, electronic devices and systems penetrate more deeply into all aspects of people's daily life. Any electrical or electronic device changing voltage and currents can be a source of Electromagnetic Interference (EMI), EMI becomes a serious and increasing form of environmental pollution, which has a negative impact on people's daily life, or can even constitute a threat to a person's safety.

The research has been carried out through the following aim and objectives.

1.1 Aim and Objectives

1.1.1 Aim

The aim is to provide integration between FMEA-based Failure Documentation and the A3 Thinking template for problem solving in order to realise knowledge capturing and provision at the design stage. The design quality could be enhanced by dynamic knowledge capturing and provision in order to guide the engineer to find practical solutions to solve current failures and avoid recurrence.

1.1.2 Objectives

The objectives of the project are as follows:

1. Synthesise the good practices of using FMEA and A3 thinking through a literature review.
2. To analyse the role and capability of FMEA and A3 thinking in capturing and communicating knowledge to support the generation of an improved design solution.
3. Design a logical linkage between different elements of the two templates (FMEA-based Failure Documentation and A3 Thinking template), which is the integration for problem solving during the design stage and supporting knowledge capturing, visualisation and provision for reusing.
4. Validate the integration via case study on automotive electrical product development within EMC consideration in collaborative company.

1.2 Research Questions

1. Would an improved design be achieved by establishing a linkage between design problems and knowledge that provide solution?

2. Would design quality be enhanced by finding a method which could dynamically capture and provide knowledge through problem solving from an engineer's perspective?

1.3 Structure of the report

Chapter One: the report begins with an introduction to the context of the research, including the background of the research, FMEA and A3 Thinking, in addition, a summary of EMC, which will form the focus of the case study, is provided to state the situation of the research. Aim and objectives are also outlined in this chapter.

Chapter Two: consists of the Research Methodology with detailed specific tasks in each stage and deliverables.

Chapter Three: consists of literature reviews of knowledge management, Knowledge Life Cycle, including Lean Knowledge Life Cycle, Problem Solving Process with related tools and approaches, the state of art of FMEA and A3 thinking, including their templates, definitions and successful applications in industries to capture their best practices. Related knowledge about EMC testing and EMC Design Issues is presented. At last, the research gap is identified.

Chapter Four: Industrial field study is carried out in this chapter, consists of an analysis on the AS-IS product development process of the collaborating company in order to identify the current limitation. In addition, document research and face to face interviews are carried out with analysis on the results.

Chapter Five: The development of integration between FMEA-based Documentation and A3 Thinking template is described in this chapter, based on the case study. Firstly, the interrelationship between FMEA and A3 Thinking templates is described to propose the linkage between FMEA Failure Documentation and A3 Thinking template. Then the To-Be scenario of design and development process with EMC consideration is presented, each step being defined in detail with supporting tools or methods. The case study is carried out to illustrate the concept within the use of integration of FMEA-based Failure Documentation and A3 Thinking. Finally, the conclusion of the integration comes up.

Chapter six: This chapter is carried out with discussions, conclusions and future work. The contribution to knowledge, research limitation and recommendation for future work are also stated.

2. Research Methodology

This research will consist of four stages with specific tasks and deliverables to achieve the final expected results.

Stages	Key Tasks	Deliverables
1. **Literature Review**	1.1 Literature review on Knowledge management, Knowledge Life cycle, application of FMEA and A3 Thinking; 1.2 Identify the research gap.	1. Best practice of FMEA and A3 thinking on knowledge management 2. Identified gap
2. **Industrial Field Study**	2.1 Analyse the files regarding EMC issues; 2.2 Conduct face to face interviews and data analysis; 2.3 Identify challenges of current status.	Current Industrial Limitations
3. **Design and develop the integration of Failure Documentation and A3 template**	3.1 Analyse the interrelationship between elements in FMEA and A3 Thinking templates; 3.2 Design the integration of Failure Documentation and A3 Thinking template.	Integration of Failure Documentation and A3 Thinking template
4. **Validation**	4.1 Validate the integration through case study with the collaborating company.; 4.2 Present the integration to collaborating company, and evaluate it through experts' view.	Validated integration of Failure Documentation and A3 Thinking template

Table 2. 1 Research Methodology

Stage 1: Literature Review

Task 1.1 The literature review is performed regarding Knowledge Management, Problem Solving Process and related tools and approaches, FMEA and A3 Thinking and their successful applications in industry to get sufficient understanding, with the resources from Cranfield University Library, and academic database, such as Google Scholarship, which will be helpful in establishing linkage between FMEA and A3 Thinking.

Task 1.2 Find out the applicability of integrating FMEA and A3 Thinking template for knowledge capturing and provision during problem solving, according to the following questions:

1. What is the advantage of using FMEA and A3 Thinking templates in problem identification and problem solving?

2. What kind of linkage could be developed between different elements in FMEA and A3 Thinking templates?

3. Where is the opportunity of using FMEA and A3 Thinking templates to achieve knowledge capturing and provision?

Stage 2: Industrial Field Study

Task 2.1 Interviews with engineers involved in product design and development process is performed in the collaborative company. A semi-structured questionnaire is used to collect data during the interviews. Analysis is also performed on the files regarding EMC failures provided by the company to have an overview of the current industrial practices of problem solving, knowledge capturing and provision.

Task 2.2 According to the results of interviews response and file analysis, identify the current limitations of practice in knowledge capturing and provision, and find out the opportunity of improvement with current practice of EMC product development in the collaborating company.

Stage 3: Design and develop the integration of FMEA and A3 Thinking template

Task 3.1 Design the integration of Failure Documentation and A3 Thinking template:

1. Analysis of the necessity of the elements that will make up the integration;
2. Definition of each element;
3. Develop the linkage between different elements in the two templates.
4. Using the integration to illustrate the concept: using standard templates of failure documentation and A3 report to document the failure, and solve it. Then the solution which could help pass the test will be

generated as knowledge, and present to engineers in the form of checklist questions to avoid recurrence.

Stage 4: Validate the integrated approach

Task 4.1 Validate the integrated approach through case study within the collaborating company.

Task 4.2 Evaluate the case study result using the perspectives of experts from the company.

3. Literature Review

3.1 Introduction

The purpose of this chapter is to describe the literature review of knowledge life cycle (KLC), knowledge management, the state of the art of FMEA and A3 Thinking with their successful applications in industries, in order to find out the opportunity of integrating FMEA and A3 Thinking template to achieve knowledge capturing and provision at design stage. As a case study will be carried out to validate the research result, related knowledge about EMC test and EMC Design Issues is presented.

3.2 Knowledge Management

Nowadays, more organisations in the global environment are likely to agree with the significance of knowledge which could enhance organisation's competitiveness. As a result, Knowledge Management has become more widely discussed in most of the organisations. For example, in the Proquest article database, around 45 articles were related to this concept in 1995 (Carlucci, Marr and Schiuma, 2004), while the number dramatically increased to about 8000 in 2006 (Álvaro, 2006). The purpose of Knowledge Management is to improve the ability of individuals in organisation, thereby enhancing their performance and benefiting the organisation.

Knowledge, defined as true belief (Nonaka and Takeuchi, 1995), is a kind of more structured and explicit content, which is complex, and accumulated the expertise from individual (Davenport and Prusak, 1998). Basically, knowledge could be classified into two types: tacit and explicit. Tacit knowledge, including insights, intuitions and hunches, is hard to share because of the difficulty for expressing and formalizing. In contrast, explicit knowledge can be presented with figures and words, shared formally and systematically, in the form of data, specifications, and reports, etc.

3.2.1 Conversion of Knowledge

Knowledge management is defined that organisation can systematically take actions with disciplines, in order to obtain the greatest value from the knowledge available to it (Marwick, 2001). It means the company should pay attention to the actions in which knowledge will be transformed between its tacit and explicit forms. As shown in Table 3.1, through organisational actions, the knowledge will be created, shared, presented and made available to others.

Tacit to Tacit ***Socialisation*** e.g. team meetings and discussions	Tacit to Explicit ***Externalisation*** e.g. Dialog within team, answer questions
Explicit to Tacit ***Internalisation*** e.g. Lean from a report	Explicit to Explicit ***Combination*** e.g. E-mail a report

Table 3. 1 Conversion of knowledge between tacit and explicit forms(Marwick 2001)

1) **Socialisation (tacit to tacit):** Socialisation always takes place in people's communication with tacit knowledge. For example, during the meetings, knowledge sharing is often processed without creating explicit knowledge, and it is suggested that socialisation could be more effective when it happens between people with a common culture and working together (Davenport and Prusak, 1998).

   During the activities, it is typical that experiences are described and discussed, in which information technology is supposed not to help a lot. However, some examples of groupware, such as Lotus Notes (Kalwell et al., 1988), provide an environment, in which users could conduct meetings, presentations, have discussions, and share documents. The importance could be enhanced if a team is geographically dispersed without meeting face to face.

These activities could be summarised as informal events. In the organisation, by providing an open environment for communication among members for sharing ideas, socialisation is initiated and encouraged. Mutual confidence will increas; the teams would reach a new level and/or more mature agreement than if individuals were left to obtain information on their own (Alavi and Leidner, 2001).

2) **Externalisation (tacit to explicit):** Because of the nature of tacit knowledge, it is difficult to transfer it to explicit knowledge, unless performing conceptualisation, elicitation, and ultimately representation are performed to capture it in explicit form.

   The transfer of knowledge from tacit to explicit is usually started by discussion, or meeting in a sharing manner, and presented as an explicit profile. For instance, experience workshops, in which people from a project team with their own experience and expertise, open communication by addressing questions of what could be learned from the project, how they judge its success. Talking with such a purpose and reflecting on such experiences could help contribute to knowledge articulation.

3) **Combination (explicit to explicit):** Compared to externalisation, explicit knowledge could be easier to share by means of documents, education and training. A set of technology, such as the implementation of computer science, could help foster knowledge creation, enriching and reconfiguring it, to make it more applicable. A typical activity in a company is to document the knowledge, such as best practice cases and experience reports (Martin and Anja, 2005), into a shared database.

Information technology could contribute significantly at this stage of knowledge management. Once explicit knowledge is formed, technology could help people reorganise it in a way of making it available to more others. The quality of knowledge here rests in how useful that knowledge is to others. For example, one way to measure the quality of knowledge is by performing citation analysis, to identify the frequency of using the knowledge (Marwick, 2001).

A common problem when using the knowledge database is searching, resulting in many documents irrelevant to the user's need, while a well-structured and classified database would lessen that probability.

4) **Internalisation (explicit to tacit):** Internalisation is always acted by individuals. By understanding the tacit and explicit knowledge shared in the activities mentioned above, individuals have the opportunity to creating their own tacit knowledge. A simple way to realise internalisation is through learning. However, a larger amount of information and it is necessary to integrate and filter information from different sources in order to make better decisions, results in challenges to knowledge users (Shenk, 1998).

One way to motivate people to capture the knowledge and reuse it is to show the benefit from the process. A lot of research has been performed to develop effective knowledge management models. However, the quality of the knowledge captured varies. The usefulness of the knowledge lies in measuring its quality rather than quantity and the frequency with which it has been used. Generally, the potential use of the knowledge requires specific classifications that are based on the nature of the projects and background.

Obviously, certain goals should be met when referring to effective knowledge management. As a new kind of company resource, it should be (Karl et al. 1997):

- Delivered at the right time
- Available at the right place
- Present in the right shape
- Satisfying the quality requirements
- Obtained at the lowest possible costs.

3.3 Knowledge Life Cycle

The term Knowledge Life Cycle (KLC) was used by Borghoff and Pareschi (1997) to describe Nonaka and Takeuchi's (1995) SECI process, standing for the four modes of knowledge conversation, transferring between tacit and explicit knowledge. Firestone and McElroy (2003) used the term KLC to describe "a process that produces knowledge with a conceptual framework that provides a cognitive map of these processes".

In past years, researchers have developed several KLCs according to their research aim within the discipline of knowledge management:

1) McElroy's (2003) KLC consisted of two main processes: Knowledge production and knowledge integration, mainly concentrating on stages of individual and group learning, knowledge claim formulation, information acquisition and knowledge validation.
2) Jashapara's (2004) KLC is made up of five stages: (1) discovering knowledge; (2) generating knowledge; (3) evaluating knowledge; (4) sharing knowledge; (5) leveraging knowledge.
3) Bukowitz and Williams' (2000) KLC is divided into tactical and strategic dimension. The tactical dimension consists of four stages, i.e. get, use, learn and contribute, driven by met and lost market opportunities or demands. The strategic dimension includes stages of assess, build and sustain, and divest. There are knowledge-based assets between the tactical and strategic dimensions, which

include knowledge repositories, relationships, organisational intelligence, etc.

According to the basis of performing research on these approaches to Knowledge Life Cycles, three major stages could be generated in Knowledge Life Cycle as (Kimiz, 2005), Table 3.2 shows the detail:

1. Knowledge capture and /or creation.
2. Knowledge sharing and dissemination.
3. Knowledge acquisition and application.

McElroy's (2003)	Jashapara's (2004)	Bukowitz and Williams' (2000)	Knowledge Life Cycle
Individual & group learning	Discovering knowledge	Get	Create/capture
Knowledge claim validation	Generating knowledge	Use	Create/capture
Information acquisition		Learn	Create/capture
Knowledge validation	Evaluating knowledge	Contribute	Create/capture, contextualise
Knowledge integration	Sharing knowledge	Assess	Share, disseminate, assess
	Leveraging knowledge	Build/sistain	Acquisition and application
		Divest	update

Table 3. 2 Mapping of Knowledge Life Cyles

During knowledge capture/creation to knowledge sharing and dissemination, the knowledge is assessed, and then contextualised in order to be understood (“acquisition”) and used (“application”). Feed back is preceded to update the knowledge in the first place. This process is outlined in Figure 3.1 (Kimiz, 2005):

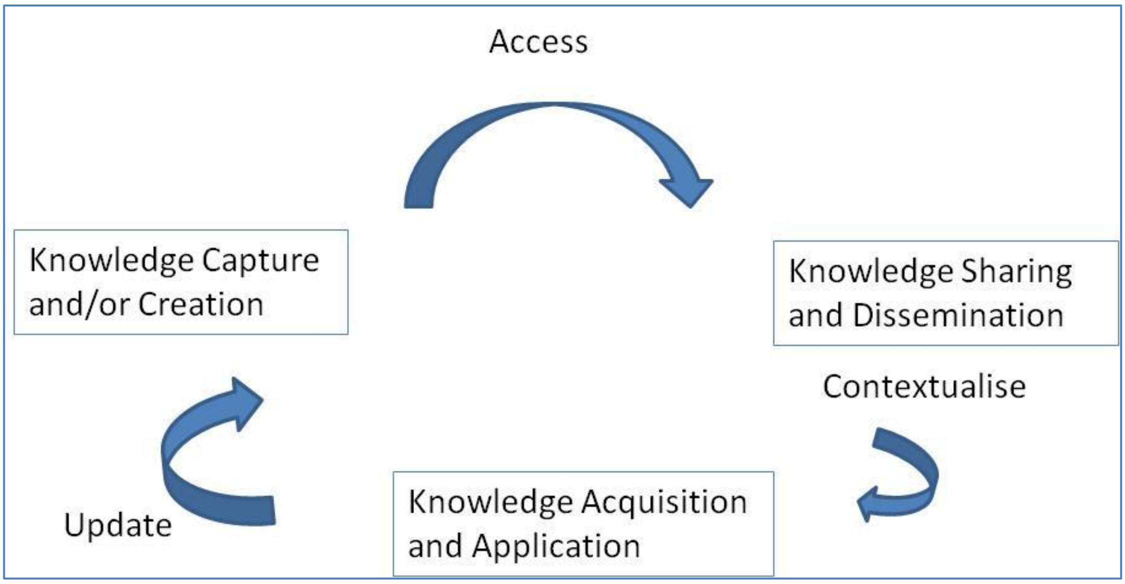


Figure 3. 1 Knowledge Life Cycle (Kimiz, 2005)

3.3.1Lean Knowledge Life Cycle (LeanKLC)

The word ‘Lean’ originates from Taiichi Ohno, of Japanese Toyota Development. The lean principles proposed by Womack and Jones (2005) are highlighted as: (1) specifying 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’ 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 & Jones 2005)

LeanKLC is a part of the Lean Product and Process Development (LeanPPD) project, which is funded by the EU-FP7. The purpose of LeanKLC is to develop a Lean

Knowledge-Life-Cycle that will provide companies with methodology to create, capture and re-use knowledge in the product development process. This will enhance value creation based on proven knowledge in order to enable the application of lean thinking in product design and development (Maksimovic, 2011).

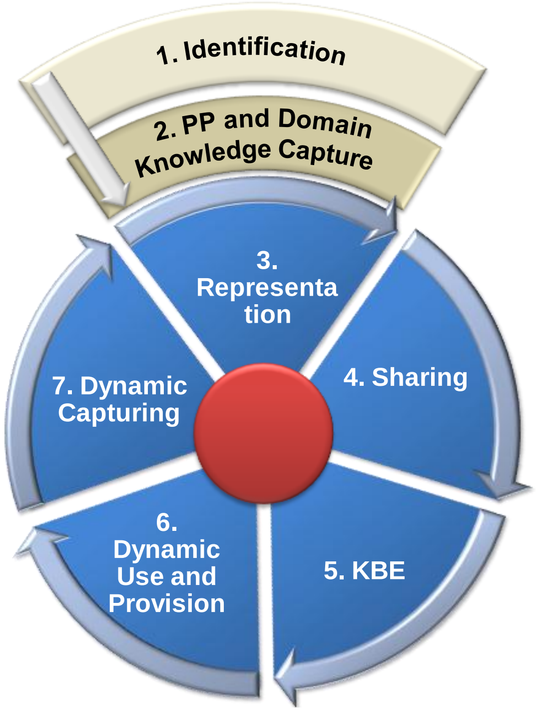


Figure 3. 2 LeanKLC (Maksimovic, 2011)

As shown in Figure 3.2, the main stages of the Lean KLC are as follows (Maksimovic, 2011):

1) **Stage 1:** Knowledge Identification.

   Localise and identify the useful knowledge that the organisation has and needs. Traditionally, the methods, for instance, interviews and questionnaires are still common approaches for knowledge identification.

2) **Stage 2:** Previous Projects (PP) and Domain Knowledge Capture

   The identified knowledge in Stage 1 will be captured and structured. It will influence and guide the organisation to structure its knowledge database. Currently, some techniques, such as Product Data Management (PDM) and Product

Lifecycle Management (PLM) systems, are commonly used in many companies.

3) **Stage 3:** Knowledge Representation

   Only the domain knowledge captured in Stage 2 will be represented in this stage, and should be represented using a formal method.

4) **Stage 4:** Knowledge Sharing

   The knowledge captured from previous projects and newly generated from the continuous loop of LeanKLC will be stored together in a structured database. It is expected that the users could quickly refer to the required knowledge for help.

5) **Stage 5:** Knowledge Based Engineering

   The application of the knowledge capturing, representing and sharing model will be realised by developing a software system.

6) **Stage 6:** Dynamic Knowledge Use and Provision

   The knowledge could be provided to product development engineers to support decision making. The knowledge provision could allow the filtering of the most relevant knowledge in previous project, in form of easy-use methods, such as design templates, checklists, trade-off curves and A3 problem solving templates.

7) **Stage 7:** Dynamic Knowledge Capturing

   Through new product design and development, knowledge should be dynamically captured. In this stage, it is important to keep the dynamic dimension of the LeanKLC running. In addition, the knowledge capturing has to be consistent with the tailored tool set and integrated accordingly in the product development process.

The continuous loop of LeanKLC could take place anywhere within the defined implementation, which means knowledge creation, representation, sharing all contribute to value creation.

3.4 Problem Solving Process within Related Approaches

3.4.1 Problem Solving Process

Generally, problem solving process would involve data collection, causal factor charting, root cause identification, and recommendation generation and implementation. It has been classified into 6 steps, including Problem Identification, Problem Team Assignment, Problem Analysis, Possible Solutions, Evaluation, and Remedial Actions (Dale, 1994). The following paragraphs in this section will detail the process with relative techniques:

1. **Problem Identification**

   Problems could have various inputs, such as design errors, test failures, customer complains, unconformity to requirements, statistical analysis result. Problems do not only cover current negative situation, but also potential problems and opportunities for improvement.

2. **Problem Team Assignment**

   Depending on the complexity of the problem, it usually needs people from different functional department to form a team in order to solve complicated problems, while some problems could be dealt with individually.

3. **Problem analysis**

   In the problems analysis step, it is necessary to collect all available information to help the problem solver to understand the problem. These information, such as, if applicable, test report, statistical analysis result, design or process information would be analysed to find the causes of the problem.

   Root Cause Analysis (RCA) is a common terminology in quality management. It is necessary to understand the root cause of any problem in order to avoid recurrence in future. Basically, RCA is looking for three types of causes as following descriptions (Mind Tools Ltd, 2010):

- Physical causes – tangible or physically of the product or system e.g.: car break, production conveyor and computer.
- Human causes – the possibility of people or manpower that not doing proper work procedures.
- Organisational causes – the company policy, technology system or process procedures that produced problem causes.

In Problem Analysis, common tools applied are like Cause-and-Effect Diagram (CED), Interrelationship Diagram (ID), Current Reality Tree (CRT), and the 5 Whys analysis, which are introduced in the following paragraphs.

Cause-and-effect Diagram (CED)

The Cause-and-Effect Diagram (CED) is popularised by Kaoru Ishikawa in 1960s, with other names of Ishikawa diagram or fishbone diagram. Subsequently, as a popular and effective quality control tool, CED was widely used in most of Japanese industries (Ishikawa, 1982). It is regarded as one of the seven basic tools in quality management, as illustrated in Figure 3.3:

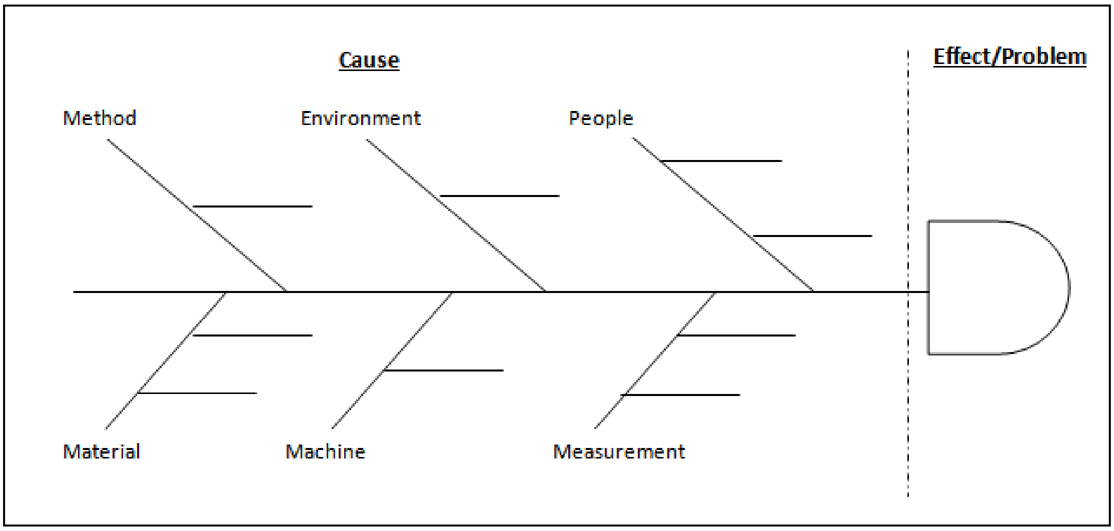


Figure 3. 3 Ishikawa Diagram/Fishbone Diagram (Ishikawa, 1982)

The Ishikawa diagram is divided into two sections which are effect or problem and cause. The causes in the diagram could be derived from brainstorming sessions, and mainly categorised into 6 groups: Method, Environment, People, Material, Machine, and Measurement. This diagram could help problem solver visualise the 'cause to effect' process, as a reference for proposing solutions.

5 Whys

As a simple tool to discover the root cause of a problem, 5 whys is commonly used in quality control (Karn, 2009). 5 whys is strongly used at the first stage in the design process for design requirements and customer value identification (Fantoni et al., 2006). In Toyota, asking why five times is believed to lead to the conclusion. Actually, the number of times asking why depends on the complexity of the problem (Karn, 2009). It helps the problem solver to find the root cause of the problem quickly by using the 5 whys worksheet, as Figure 3.4 shows.

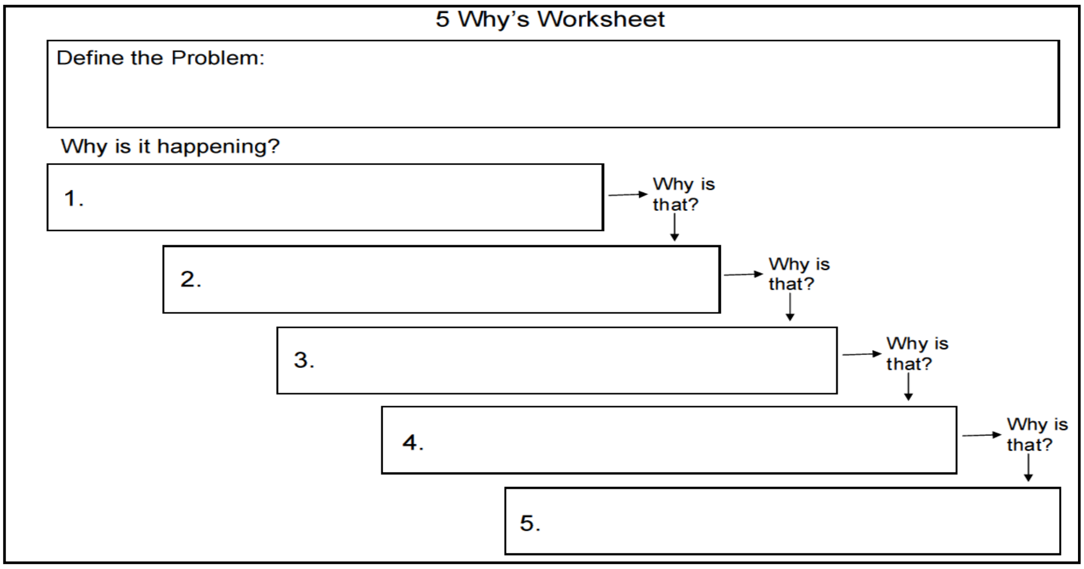


Figure 3. 4 5 why's worksheet (Olivier, 2009)

However, usually the result of using 5 whys is based on personal opinion. Different people carry on 5 whys on a problem may come up with different results (Karn, 2009). It was recommended the person or the team should have enough expertise to have an accurate analysis result.

Interrelationship Diagram (ID)

ID was originally developed by the Society of Quality Control Technique Development in association with the Union of Japanese Scientists and Engineers (JUSE) in 1976. It aims to clarify the cause relationships of a problem in order to identify a proper solution. It uses arrows to show cause-and-effect relationships among a number of potential problem factors. The format is almost unrestricted. it places the major problem in the central with related factors around to show the relationship. Figure 3.5 shows an example of Interrelationship Diagram.

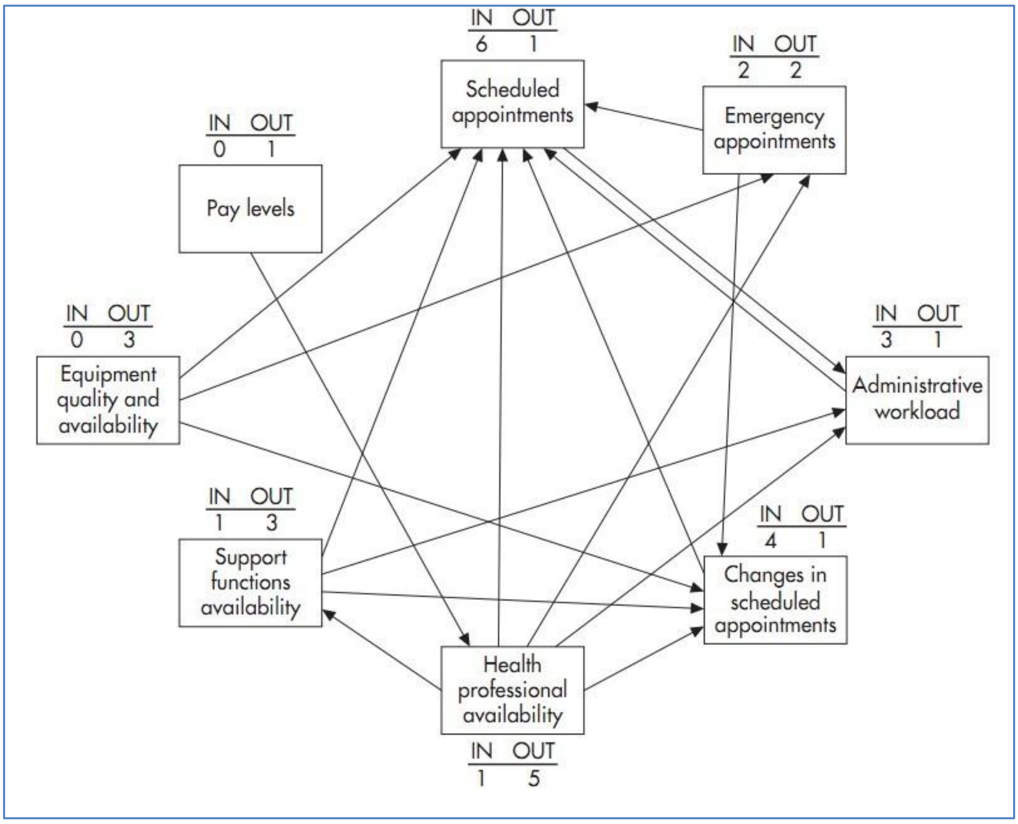


Figure 3. 5 Example of Interrelationship Diagram

It is required to use concise phrase as opposed to isolated words to state each factor. After all the relationships being validated, count the number of arrows in and out. A factor with more “out” arrows than “in” arrows could be regarded as a cause, while one with more “in” arrows is an effect.

Similar to 5 Whys, ID has its disadvantage, it may rely heavily on the subjective opinion about factors relationships and become quite complex or hard to read (Andersen and Fagehaug, 2000)

Current Reality Tree (CRT)

CRT was firstly introduced as a tool for addressing problems by relating multiple factors rather than isolated events. It helps users to find the relationship between undesirable effects of the problem (Doggett, 2005). CRT uses entities and arrows to state a problem. Entities could be causes, effects, or both (Dettmer, 1997). An unique symbol, called oval or ellipse, is used to show the relationships between interdependent causes. The word "sufficiency" is always used to assess if the cause is sufficient to create the proposed effect. The relationships between entities is regarding as an "if-then" statement. Figure 3.6 shows an example of CRT application

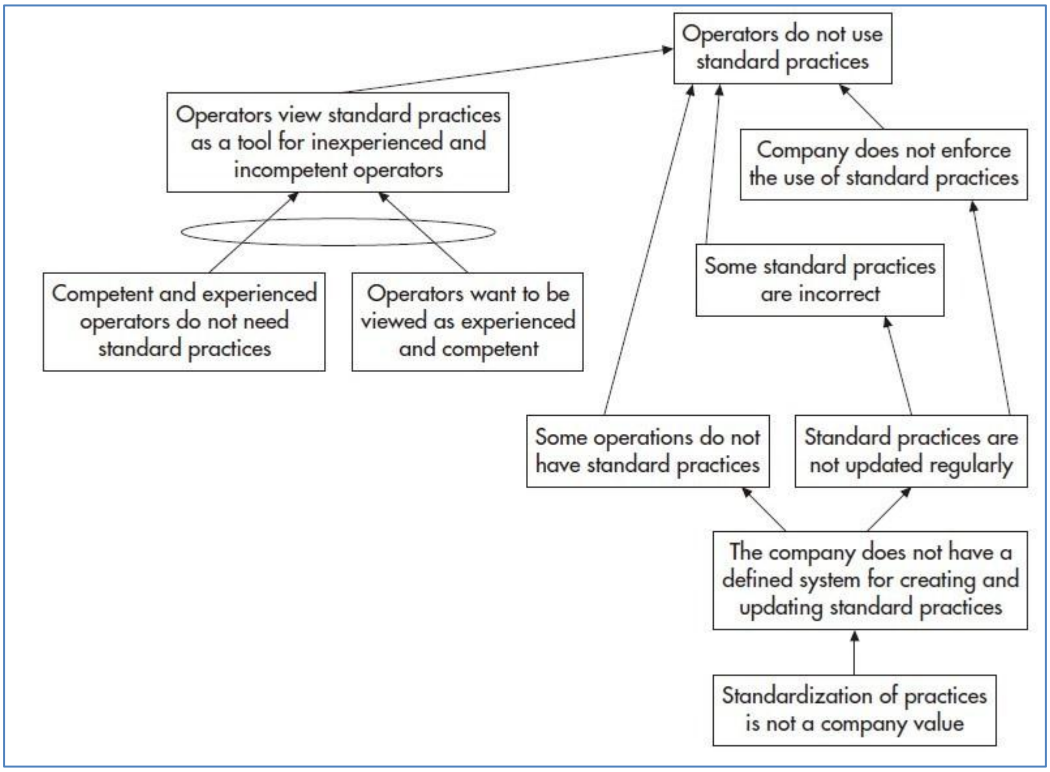


Figure 3. 6 An Example of Current Reality Tree(Doggett, 2005)

It was concerned on CRT that the complexity of construction when initially starts CRT, may cause difficulty on application, which will be time consuming.

The literature review also reveal that these tools applied to identify root cause can be combined together, for example, Cause-and-Effect Diagram and 5 whys, depending on the complexity of the problem.

4. **Possible solutions**

   Once the root cause of the problem is identified, problem solvers begin to search for possible solutions. With many problems, more than one solution may be required to remedy a situation.

5. **Evaluation**

   This step is to evaluate which one of possible solutions generated in last step could have the greatest effect to solve the problem. Measurements should be established to assess the effect, such as cost, feasibility, and resistance to change.

6. **Remedial action**

   Solution implementation and follow-up actions is required in this step to solve the problem.

3.4.2 Problems Solving Approaches

This section introduces two approaches with their templates that have been widely used in problem solving activities and documentation.

Problem Analysis Flow Chart (PAF)

The problem analysis flow chart is a problem solving approach that utilises the 5 whys for root cause analysis. This approach has been used in manufacturing processes. All these problem solving processes require continuous observation on the process, and performing tests on proposed solutions and validate their effectiveness several times (Sproull, 2001). It has ten major steps which are outlined in Table 3.3 below:

Steps		Detail
1	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.
2	Symptoms	Symptoms are faults that need to observe. This step including faults, signs of problems, simultaneous and senses.
3	Changes	The change might have occurred prior to the onset of the problem.
4	Relevant data	Any relevant information or data that can help resolve the problem.
5	Defect free configurations	Help to eliminate potential problems causes.
6	Distinction	Always compare the process (or object) WITH the problem to the process (or object) WITHOUT the problem, not vice versa.
7	Causal chains	Causal chains are the logical steps from symptoms to the cause of problem. Each step is the cause of the next step and the effect of the previous one.
8	Test, corrections, results and conclusion	All these activities will reveal the potential root causes.
9	Most probable cause	Review all the analysis and discuss the result by listing the underlying cause of the problem.
10	Short term and long term corrections and controls	The short term action- without much effort and the problem is fixed on the spot. The long term action – require more effort and the problem will be continuously improved.

Table 3. 3 The Detail Steps in PAF (Sproull, 2001)

All the test and corrections results are analysed and concluded in the causal chains box (Appendix 1 & 2). This causal chain is a conclusion and could be used as future reference for similar potential problems. The advantage is that an inexperienced person looking at the PAF chart will be able to understand clearly how to solve a similar problem.

8 Disciplines (8D)

The ‘8 disciplines’ (8D) was first popularised in the 1960s and 1970s by the Ford Motor Company (Hawker, 2008). It’s a formal and disciplined approach developed to solve complex problems, using a combination of effective techniques and tools (QAI, 2010), with regard to cost reduction, efficiency, effect on customers and other impact to organisation. The ‘8 Disciplines’ of the approach for problem solving are showed in Table 3.4:

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

Table 3. 4 The 8 Disciplines of Problem Solving (Arnot, 2004)

Table 3.5 shows the statistical tools utilised in ‘8D’ where there are inter-relations between previous problem solving techniques, e.g. ‘5 whys’ and ‘Cause-and-Effect Diagram’. In the 8D template (Appendix 3), the solutions are represented using charts, diagrams and open-ended questions.

	Step 1: Define Concern	Step 2: Establish Team	Step 3: Initial Analysis	Step 4: Immediate Actions (Containment)	Step 5: Diagnose Root Cause(s)	Step 6: Permanent Action(s)	Step 7: Prevention	Step 8: Validation
Flowcharts	X		X	X	X	X		
Brainstorming			X		X			X
Force Field Analysis			X	X	X	X		
Cause and Effect			X		X			
Interviewing	X	X	X		X	X		X
Surveying	X	X	X		X	X		X
Market FeedBack - Customer Input	X	X	X	X	X	X	X	X
Checksheets			X	X	X	X		X
Histograms			X	X	X	X		X
Pareto Analysis	X		X		X	X		X
Run Charts			X	X	X	X		X
Pie Charts			X	X	X	X		X
Criteria Rating Forms			X		X	X		X
List Reduction			X		X	X		X
Weighted Volume			X	X	X	X		X
Gantt Chart			X	X	X	X		X
PERT Chart				X	X	X		X
Supplier Input		X			X	X	X	X
FMEA						X	X	
Control Plan						X	X	

Table 3. 5 Statistical Tools for 8 Disciplines by Arnot (2004)

3.5 Failure Mode and Effect Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) keeps on developing since it was firstly raised in the aerospace industry in the mid-1960s (Barnard, 1996; Savcik, 1981). In 1977, Ford Motor Company accepted the method and started to promote it. FMEA is a systematic method with procedure to analysis potential failure modes in product development and operations management, allowing classification according to the severity and likelihood of the failures. A successful application of FMEA could help a team to identify potential failure modes based on knowledge and past experience with similar products or processes, in order to avoid recur of them with the minimum effort and resource expenditure, then reducing cost in product or process development. Documentation will be maintained throughout the whole process of FMEA. The data and information will include the current status of product design and development, processes design, the potential failures, root causes and solutions to eliminate potential failures. The documentation system should have the function of retrieving previous failures of product design and manufacturing process design (McDermott, 1996; Dale, 1999 and SAE J1739, 2002).

The advantages of effective application of FMEA could be summarized as follows (Paul, 1998):

a) Save on development cost
b) Serve as a guide for more efficient test planning
c) Assist in the development of cost effective preventive maintenance
d) Provide insight for designing built-in tests
e) Minimize unforeseen events when designing or validating a process
f) Provide a quick reference for problem solving
g) Reduce engineering changes
h) Improve customer satisfaction
i) Provide a way of tracking the design
j) Minimize unnecessary controls in the process
k) Identify safety concerns for validation
l) Provide insight for robust design against customer habits

Generally, FMEA could be categorized into two types: DFMEA (Design FMEA) and PFMEA (Process FMEA). According to their different purposes, DFMEA and PFMEA are usually implemented for product design evaluation and manufacturing process assessment respectively.

3.5.1 Procedure of Failure Mode and Effect Analysis

A successful application of FMEA could be depicted in three main stages, as illustrated in Figure 3.7 (Teng and Ho, 1996).

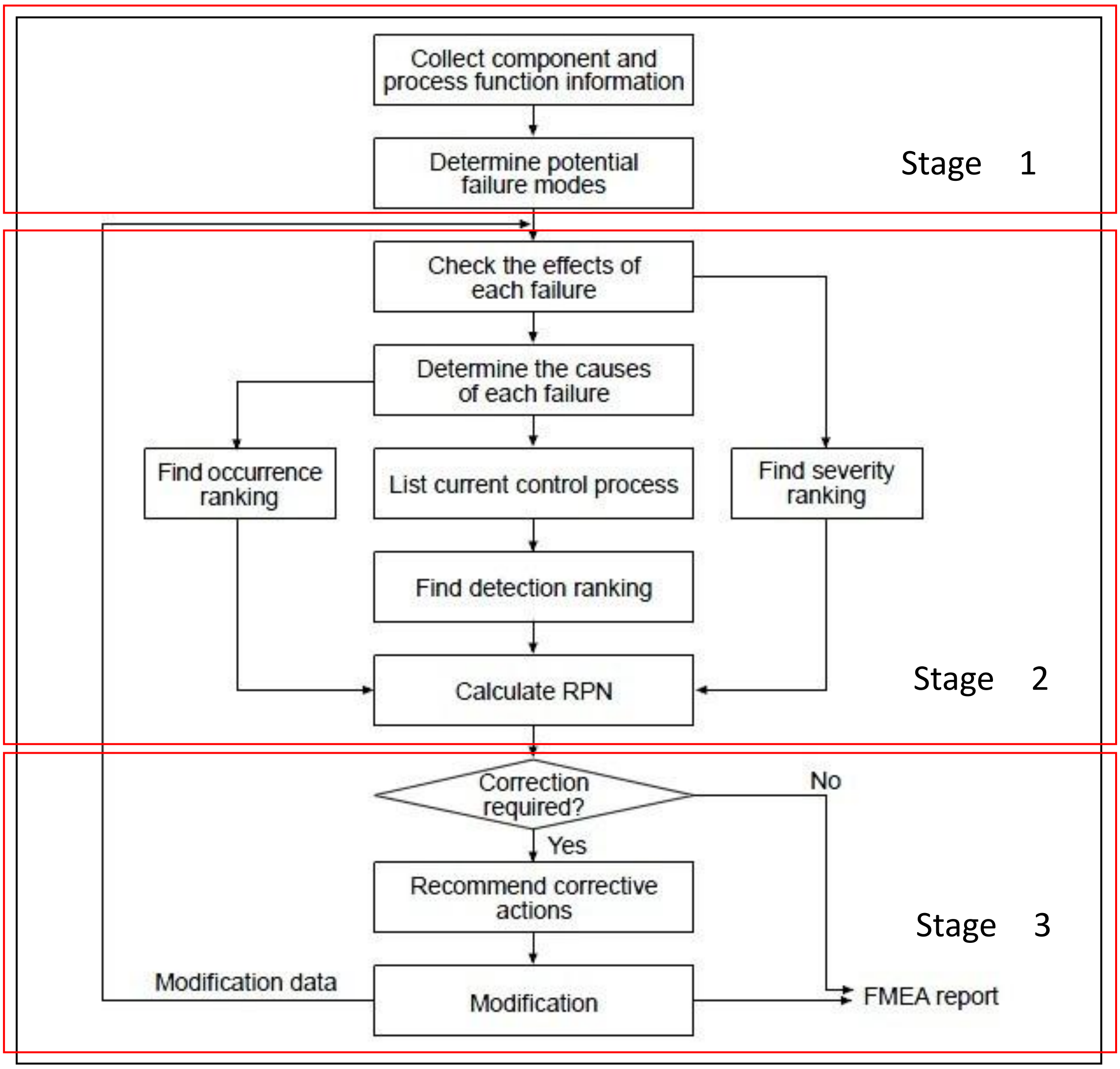


Figure 3. 7 Failure Mode and Effect Analysis Procedures (Teng and Ho, 1996)

Three key steps exist in the FMEA process, which need a FMEA team to obtain qualified expertise in different field related to the project:

The first step is the FMEA planning, which includes the definition of Failure Mode with three tailored rating scales (Severity, Occurrence and Detection). To ensure effectiveness and efficiency of FMEA, it is suggested that ground rules should be established to help every member of the FMEA team attain common understanding and agreement in this planning stage. After that, an overall assessment will be performed regarding the whole system or project to determine all the important product or process functions. The RPN, Risk Priority Number should be developed with specified regulation based on the actual situation of the organisation. For example, regarding Occurrence, the value could be produced after the analysis of historical quality data of the products or process.

The second step will focus mainly on the effects evaluation, causes analysis and risk priority number calculation. In this stage, all the suspect causes that may contribute to a specific failure mode will be evaluated. Mostly, many of the causes probably only contribute much less than the main causes that take the majority of the failure mode. According to the calculated RPN result, the FMEA team should decide whether or not further corrective action is needed based on the regulations established in the planning stage.

The third step is performing modification to the design or process for improvement. Effective countermeasures should be made and implemented to eliminate the effect caused by the failure mode on the basis of the cause analysis results.

The following tools could be used to support failure mode identification and causes analysis (Paul, 1998):

1) Benchmarking: It is a survey that can be used to rate certain features of the organisation's design against the competition. Areas where the organisations are lagging behind the competition should serve as input for the first column of the FMEA. The results of benchmarking can serve as input for listing the functions and identifying the failure modes for the FMEA.
2) Block Diagram: It is a picture which depicts all of the design components or

subsystems as rectangles and displays their relationships within the design. It can serve as a reference when constructing the FMEA to ensure that all functions have been considered in the FMEA.

3) Ishikawa Diagram: The Ishikawa Diagram, more commonly known as the “Cause and Effect” or “Fishbone” diagram, can be used to structure the FMEA brainstorming activities.
4) Process Flow Diagram: it is a picture of the process identifying all the sequential operations of manufacturing or a service.
5) Process Mapping: Process Mapping consists of a flow chart of all the required activities that must occur in order to complete the program development project.

3.5.2 FMEA templates in applications

The most popular template for FMEA is shown in Table 3.6, 3.7(Sourced from SAE J1739, 2002; Ford Motor, 2004 and Ford Motor, 1995).

POTENTIAL
FAILURE MODE AND EFFECTS ANALYSIS
DESIGN FMEA

___ System

___ Subsystem

___ Component ______________________ Design Responsibility: ______________________

Model Year(s)/Program(s): ______________________ Key Date: ______________________

Core Team: ______________________

FMEA Number: ______________________

Page ______ of ______

Prepared By: ______________________

FMEA Date: (Orig.) __________ (Rev.) __________

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Control		Detec	R.P.N.	Recommended Action(s)	Responsibility & Target Completion Date	Action Results				
							Prevention	Detection					Actions Taken	Sev	Occ	Det	R.P.N.

Table 3. 6 Design Failure Mode Effect Analysis Format (SAE J1739, 2002; Ford Motor, 2004)

POTENTIAL
FAILURE MODE AND EFFECTS ANALYSIS
PROCESS FMEA

FMEA Number: ____________

Page ______ of ______

Item: ____________ Process Responsibility: ____________ Prepared By: ____________

Model Year(s)/Program(s): ____________ Key Date: ____________ FMEA Date: (Orig.) ____________ (Rev.) ____________

Core Team: ____________

Process Function / Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Control		Detec	R.P.N.	Recommended Action(s)	Responsibility & Target Completion Date	Action Results				
							Prevention	Detection					Actions Taken	Sev	Occ	Det	R.P.N.

Table 3. 7 Process Failure Mode Effect Analysis Format (SAE J1739, 2002; Ford Motor, 2004)

The key terminologies in the format, as shown in Table 3.6, 3.7, are defined as follows.

a) Item and function: the name or concise description of the item/function being analysed.
b) Potential failure mode: the possible situation that the item/function can potentially fail to meet the relative requirements.
c) Potential failure effect: all the effects of failure on functions may cause, which the customers or next-step of the process owners may experience.
d) Severity: a ranking measurement for the level of the impact by the failure.
e) Classification: used for identifying critical features of product design, which need special control or inspection to ensure safety functions as well as the need to conform to specifications.
f) Potential causes: direct causes of failure.
g) Occurrence: probabilities that the failure might happen.
h) Current control and detection: Actions established to contain the effect of the failure or reduce the occurrence. The detection ranking is the possibility of the failure could be detected.
i) Recommended actions: actions should be established to reduce high RPN or high severity as well as the critical characteristics, based on the root cause analysis.
j) Actions result: re-evaluate the three parameters of RPN to check if the it is reduced as expected after implementing the recommended actions. The FMEA report should be documented, and if the RPN or severity is still not acceptable, the FMEA process should be repeated to achieve the point.

3.5.3 Applications of FMEA

The format, shown in Table 3.6, 3.7 is the normal way to document the FMEA data. It is very important to reuse the information accumulated in FMEA reports. However, during a long term of implementing FMEA, the number of FMEA reports will increase dramatically, depends on the complexity of the product or process. It will be very difficult to retrieve required information from these reports. For hardcopies of these reports, the engineers will spend much more time searching for the useful information, which will reduce the effectiveness of FMEA (Teoh and Case, 2004). As a result, FMEA is only used by organisations to meet the requirements from their customer's contracts (Dale and Shaw, 1990). It indicates that even if the organisation has successfully implemented FMEA for problem identification, and created knowledge during the following problem solving activities, it will still not be satisfying unless the knowledge is shared in an effective way. In that case, many companies and organizations are developing particular models that are still based on FMEA for knowledge management with appropriate software or programs.

Currently, much of the research that has been carried out regarding knowledge capturing and provision based on FMEA mainly provides domain knowledge modelling for specific use:

a) Jiří and Václav (2011) applied FMEA procedure for Arithmetic-Logic Unit (ALU) testing. Figure 3.8 shows the FMEA report they generated.

Unit/ Function	Potential way of failure	Potential failure effect	Criti-cality	Potential cause/ Mechanism of failure	Frequ-ency	System check	Detec-tion	R.P.N
ADD Gate	Short circuit between input ports	Wrong gate function – works only with 0 at both input ports	7	Badly connected ports, oxidation or impurity in circuit	5	Production testing, experience from other systems	8	280
	Permanent input connection to 0 – shortcut to ground	Wrong gate function, only transfer of value from other input	7	Badly connected ports, oxidation or impurity in circuit	5	Production testing, experience from other systems	6	210
	Permanent input connection to 0 – shortcut to ground	Wrong gate function, output is always 0	7	Badly connected ports, oxidation or impurity in circuit	5	Production testing, experience from other systems	2	70
	Permanent input connection to 1 – short at power sup.	Wrong gate function, output is always incorrect	7	Badly connected ports, oxidation or impurity in circuit	3	Production testing, experience from other systems	6	126
	Permanent input connection to 1 – short at power sup.	Wrong gate function, output is always 1	7	Badly connected ports, oxidation or impurity in circuit	3	Production testing, experience from other systems	2	42
	Negation at input	Wrong gate function, output is always incorrect	7	Badly connected ports, oxidation or impurity in circuit	1	Production testing, experience from other systems	8	56
	Negation at output	Wrong gate function, output is always opposite	7	Badly connected ports, oxidation or impurity in circuit	1	Production testing, experience from other systems	5	35
	Random 0 or 1 at input or output	Wrong gate function, output is always incorrect	7	Presence of water, impurities or loose contacts	2	Production testing, experience from other systems	9	126
	Gate is not working	Gate is not transferring values to output	5	Unconnected output, interrupted inner circuits	1	Production testing, experience from other systems	1	5

Figure 3. 8 FMEA Analysis on unit "ADD Gate" (Jiří and Václav, 2011)

In the application, the unit is defined as the function of FMEA, and failure mode is "the potential way of failure". Criticality, Frequency and Detection are used as Risk Priority Number for risk assessment.

b) FLAME (Price et al., 1995) has been developed for the design of automobile electrical systems. The Flame system aims to provide engineers with a structured system which is capable of performing automated FMEA. The input to the Flame system includes a physical description of all the particular components and their functionalities, with specified Risk Priority Number. According to the report (Price et al., 1995), this system was only developed to the level of failure identification.

c) GENMech (Hughes et al., 1999) is for mechanical design. The GENMech project is based on other successful work regarding automating FMEA production for electrical systems, such as FLAME. GENMech attempts to minimize the effort required by an engineer when producing an FMEA. It requires an established functional model which is an overall structure of the system where FMEA would be applied.

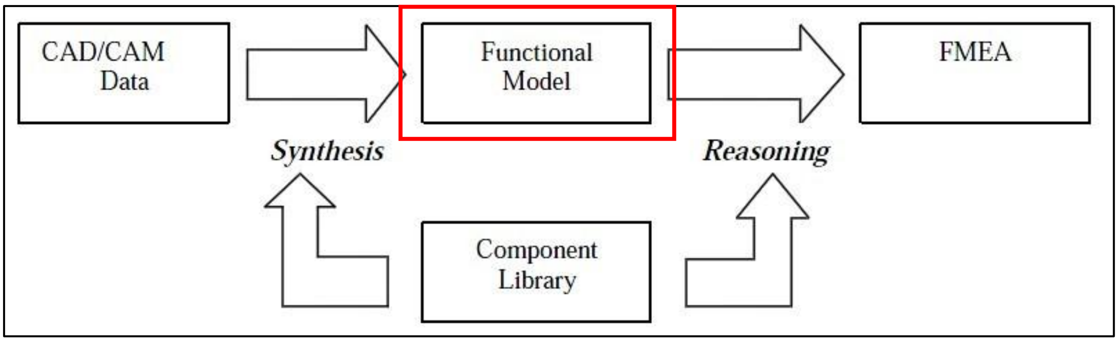


Figure 3. 9 GENMech System Overview (Hughes et al., 1999)

Figure 3.9 shows the process in GENMech System to perform FMEA. GENMech firstly synthesises CAD/CAM data into a functional model that can be reasoned about in order to produce FMEA with the use of a component library to provide data about the nature of the components in the system. The model is to identify the correct behaviour of the system. Then component failure modes are introduced to apply FMEA.

d) Atkinson et al. (1992) and Hogan et al. (1992) designed an automated fault analysis for hydraulic systems design. In this research, the researcher integrated FMEA and Fault Tree Analysis (FTA) to identify potential problems in hydraulic systems and perform fault analysis. This concept is developed with software techniques for automatically producing the FMEA report.

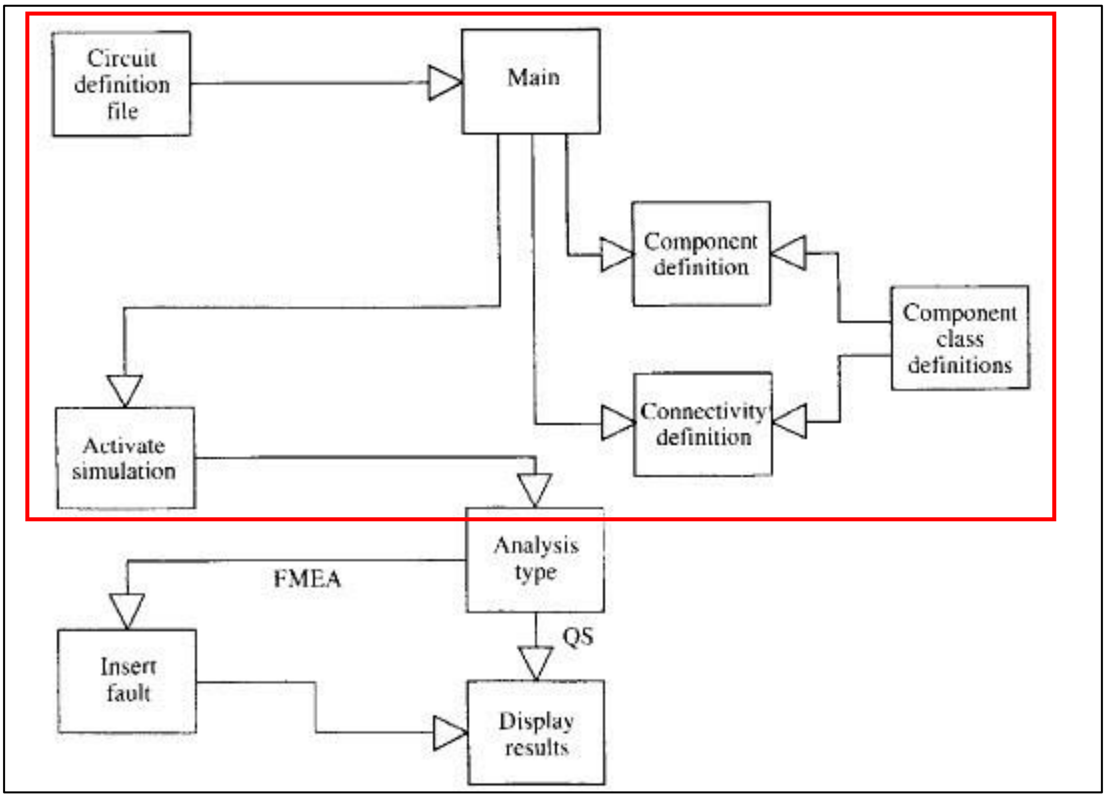


Figure 3. 10 Program Structure (Atkinson et al., 1992)

Figure 3.10 shows the process in automated fault analysis for hydraulic systems design program. Before starting FMEA, a high level module which contains all the global variables in the program needs to be developed. Within the definitions of circuit and components class, once a particular component is known, it will be possible to activate simulation and start FMEA.

e) Bouti et al. (1994) and Price et al. (1998) proposed application methods for process FMEA.

f) Eubanks et al. (1996 & 1997) suggested a generic method for both design and process FMEA. This research provides a method for developing a device behaviour model, which are cause-and-effect relationships between system-wide design variables and sub-system quality measures, to enhance reliability at the early stages of conceptual design, as shown in Figure 3.11. This method could allow designers to more quickly and rigorously define operating parameters and aid in revealing parameter interaction. It also requires (Eubanks et al, 1996; Eubanks et al, 1997):

--A behaviour model, i.e. “how (an) expected result is attained”, or the “detailed description of internal physical action based on physical principles and phenomena”;

--A structural model, which includes a physical topology of a device or system, including the components that make up the system, and relationships between the components, suitable for use in the early design stage, and linkage between models as well.

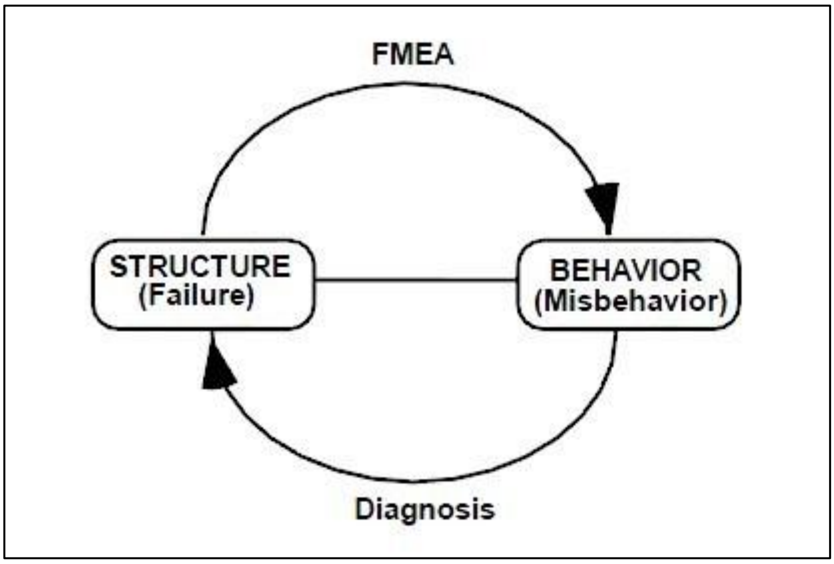


Figure 3. 11 FMEA/Diagnosis Relationship(Eubanks et al, 1996; Eubanks et al, 1997)

FMEA process will be initiated with a failed or degraded component, and FMEA owner try to identify the end-effect, which is usually described as a malfunction or misbehaviour. Diagnosis plays with the same idea, but in opposite direction, from an observed misbehaviour to the attempt of identifying the failure (Eubanks et al, 1996).

Summary of the applications of FMEA

The common points in these applications could be summarised as follows:

1) Construction of FMEA.

In order to use FMEA to identify potential failures, a systematic analysis is required to define the structure of the project where FMEA will be applied. It is said in FLAME, "the construction of the model of the system on which FMEA is to be performed is a key element in the FLAME system" (Price et al., 1995). Generally, in these applications, the Function of FMEA is always defined as a particular unit/component or process, and Failure Mode is the potential way of a failure. The parameters that will be applied for risk assessment are various, which depend on the project itself.

2) Quick FMEA

The idea of creating "Automatic" FMEA report was mentioned in some of these applications. It could be considered in that problems could be quickly identified and described in form of an FMEA report after the construction of FMEA is established.

3.6 A3 Thinking Approach

The A3 Thinking approach began in the 1960s and comprised an effective tool that the Toyota Motor Corporation used to propose possible solutions and generate a concrete structure to address the problems (Shook, 2009). A3 Thinking is an effective way to promote continuous learning by engaging collaboration. Ideally, the A3 report is a communication tool that follows evidence and logical structures (Kimsey, 2010). As a systematic approach to solve a problem on a single piece of A3-size paper, the ultimate goal is not only to solve the problem but also to make the process transparent and comprehensible in a manner that develops the thinking and learning of the problem solvers (Shook, 2009). The A3 Thinking approach helps draw the user to a deeper understanding of the problem or improvement opportunity, and guides them in addressing it in an A3 report. As an A3 report system exists in Toyota, it provides a way to cultivate the intellectual development of its peers (Sobek and Smalley, 2008).

3.6.1 A3 Thinking templates

The A3 Thinking template is shown in Figure 3.12 below:

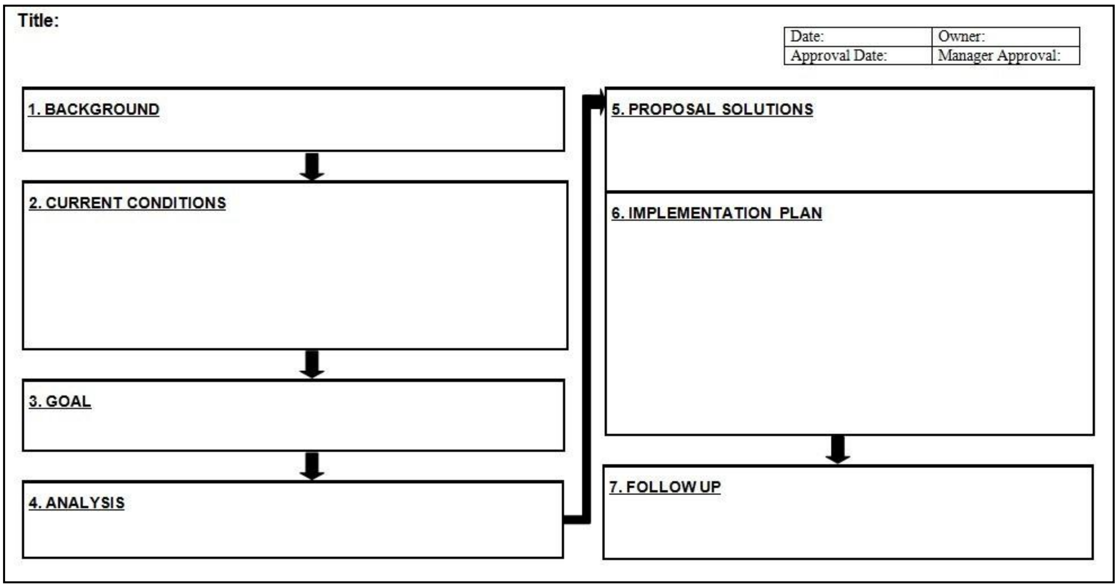


Figure 3. 12 A3 Thinking Template (Shook, 2010)

In the A3 Thinking template, before conducting the problem solving, each failure will be given a title to explain the failure, assigned its owner, date and approval, then the whole process will be represented by visualised simple sentences, charts and diagrams following seven major steps. These steps include background, current condition, future goals, root-cause analysis, countermeasures, implementation plan and follow-up action, as described in Figure 3.12.

1) **Background**. Why are you talking about it? The essential content in this element is the information necessary for readers to understand the importance and extent of the failure. It is important that the A3 report owners understand who the readers will be. To write the background of the failure requires the owner of A3 report to perform an investigation, for example, how was the failure discovered? How long has it been a failure? The answer to these questions must be presented with objective evidence. It will be helpful to obtain the information from the person

who was working on the area related to the failure.

2) **Current Conditions**. The current status of the failure will be present in this element. It is necessary to collect data, such as performance data, working samples, mapping and interviews with related workers. Define the current conditions with visual presentations (e.g. drawing, graphs, and tables, etc.).
3) **Goal**. Define the expected outcome, which should be achievable.
4) **Analysis**. Assemble a team if necessary, to perform deeper investigation into the failure, to identify the root cause. Root cause analysis tools, such as 5 whys and the fishbone diagram, could also be introduced in this stage, to help find the cause and effects of the failure. Visualise the analysis process if possible.
5) **Proposed Solutions**. Initiate practical solutions for the failure, according to the root cause found in the last step. The solutions could be in the form of design or process change, replacement of parts, or equipment adjustment.
6) **Implementation Plan**. Develop action plans to achieve the agreed future goal. Who, when, where, how, and what to be done, should be defined in the plan, and validate the results of the solutions.
7) **Follow up Actions**. To reflect what changes have been made to the system to sustain the improvement, whilst also preventing the problem from recurring.

The seven components are separately allocated on two sides of A3 paper. Meanwhile, the A3 Thinking template represents the Plan-Do-Check-Act (PDCA) cycles during the procedures.

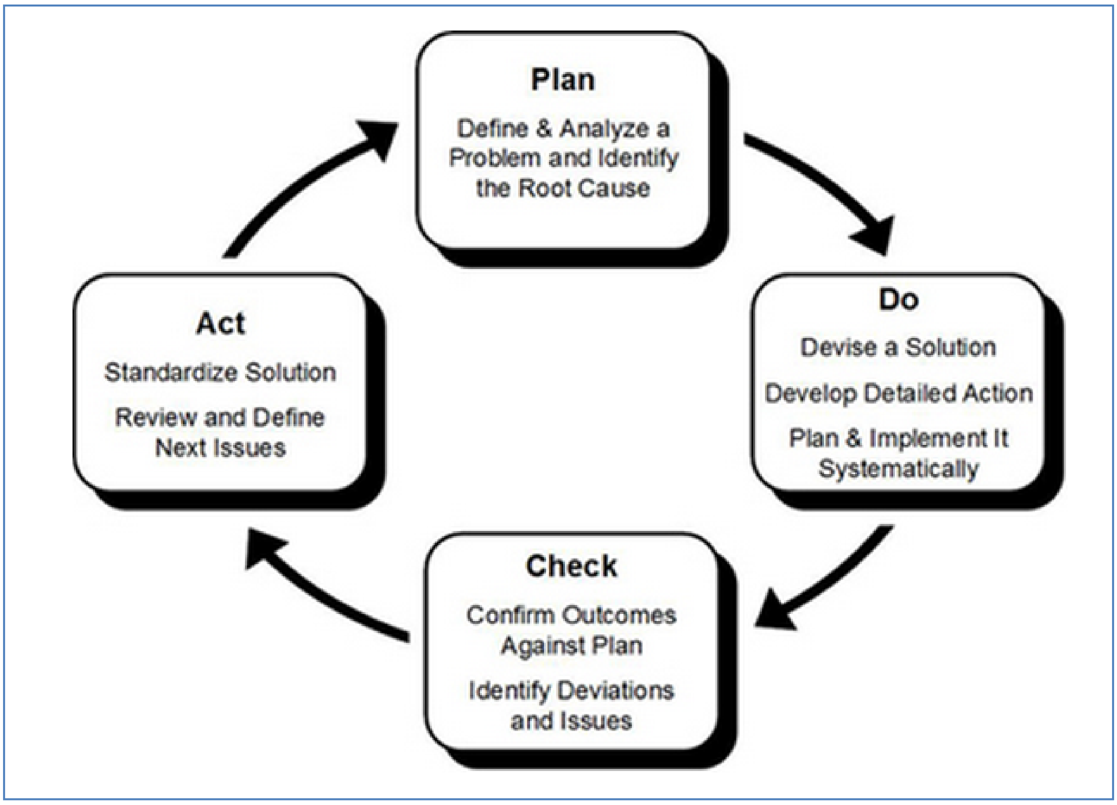


Figure 3. 13 Plan-Do-Check-Act Cycle (ASIS/BSI BCM., 2010)

The PDCA cycle, as shown in Figure 3.13, is well known as an effective model for continuous improvement. It helps organisations have the opportunity to follow the four steps for improvement or change:

1) **Plan:** Recognize the chance to improve or change, and plan. At the start of the cycle, reorganisation of improvement or change means developing an overview of the project or system should be presented to help users have a basic understanding of current status, and reach to agreement.
2) **Do:** Test the change. Proposed actions will be implemented experimentally for assessment.
3) **Check:** Review the change, assess the results, and identify lessons learnt. In this stage, the result of 'Do' will be measured and documented. Users will identify the possible effect which may occur after implementing the actions.
4) **Act:** Take actions based on the results from the Check step. Apply the beneficial plan of successful change and popularise it into widely use, or conduct another

cycle if the change is not satisfactory.

There are three main advantages for using the A3 Thinking approach (Whittier Inc., 2005):

1) The format requires conciseness and focus;
2) A3 report writers learn quickly by using pictures and other visuals to maximise the information contained in the report;
3) All of the important information stays up front, i.e. visible, unlike slide presentations during the discussion.

These advantages make the A3 report an effective support for product designers to document failure cases and reuse the knowledge in an efficient way to enhance the design quality.

3.6.3 Applications of A3 Thinking approach

As emphasized in A3 Thinking, the core of A3 thinking is the Plan-Do-Check-Act cycle (Liker and Meier, 2006). Continuous improvement could be ensured by using this technique to solve problems, gain agreement and mentor. The advantage of applying A3 Thinking is that it is visual, simple and logical, and this way of documenting and communicating information could help users more effectively solve problems. Knowledge is created during problem solving activities when A3 thinking is processed, and the A3 report is a user-friendly way to capture the knowledge and communicate with others.

As mentioned regarding knowledge transformations, tacit to explicit, explicit to explicit, and explicit to tacit, A3 Thinking is used as a standard way of communication at all levels of work throughout Toyota. Conceptually, A3 Thinking approach is a tool for communicating all issues, such as proposals, problem-solving, status updates (Shook, 2010).

Here follow some examples of A3 Thinking applications in different industries:

1) The Industrial and Systems Engineering and Engineering Management (ISEEM) department at the University of Alabama in Huntsville has been adopting A3 reports as the common language for report assignments, course administration and course evaluation (Farrington, Utley and Harris, 2007). The benefits of A3 Thinking use are not only in allowing the faculty more time to provide value added teaching, but also help them to use A3 Thinking to make sure their students understand their problems, develop appropriate countermeasures, and cultivate lessons learned (Nicholas, Gregory and Lisa, 2010).
2) Manimay and Durward introduced A3 thinking to improve the group meal therapy process in a Rehabilitation Nursing Unit (RNU) of a hospital (Manimay and Durward, 2005).

The common factor in these applications is that they have realised the effectiveness of using A3 Thinking to communicate and solve existing problems. Knowledge management of tacit to explicit, explicit to explicit were deeply involved in the process.

3.7 Electromagnetic Compatibility (EMC) Test

The purpose of this section is to state the relevant knowledge of Electromagnetic Compatibility (EMC). This research carries out a case study with an automotive supplier. In this company, Electromagnetic Compatibility (EMC) testing failures always result in a great cost of resources. They are looking for a method that could help them reduce the failures in the design stage, by generating and effectively reusing the knowledge accrued from previous issues.

Electromagnetic Interference (EMI) could be regarded as a kind of environmental pollution, compared to toxic chemical pollution, vehicle exhaust emissions or other discharges into the environment. Nowadays, a number of electronic devices are widely used in people’s daily life. These devices will frequently produce electromagnetic spectrum, which may cause interference with other electronic devices, impact their normal functions. Therefore, unexpected electromagnetic interference could result in a real economic and social threat including injury or even death (David, 2007).

As EMI is an intangible phenomenon, it is difficult for manufacturers to know if their products are electromagnetically compatible. The only real way is to conduct scientific EMC Tests to demonstrate that well-designed equipment meets legislative and contractual requirements. A production model is required during the EMC tests, these tests may need to be repeated after changes in production, to ensure product compliance is maintained. OEM parts and accessories should come with a Declaration of Conformity and be checked for compatibility with the final product's intended use (RN Electronics Ltd, 2011).

EMC is established as one of the most important requirements in the automotive system of vehicles, which has a number of electronic units to obtain the functions. 35% of the total medium sized vehicle cost concerns electronic units (Julian and Mateus, 2010). The challenge is to ensure that all vehicle electronics should be compatible with each other and relevant roadside equipments, and meet different specifications from different customers. Generally, all the electronic units with EMC requirements will go through EMC testing to verify the conformity against related requirements.

Generally, for the purposes of being able to test whether or not a device complies with the Directives or standards, EMC tests can be divided into five classes:

1. Radiated emissions - Checks to ensure that the product does not emit unwanted radio signals;
2. Conducted emissions - Checks to ensure the product does not send out unwanted signals along its supply connections and connections to any other apparatus;

3. Radiated susceptibility/immunity - Checks that the product can withstand a typical level of radiated electromagnetic pollution;
4. Conducted susceptibility/immunity - Checks that the product can withstand a typical level of noise on the power and other connections.
5. Electrostatic discharge - Checks that the product is immune to a reasonable amount of static electricity.

Considering the complexity of interferences between internal systems and components, it is difficult to estimate the real cause of a testing failure. It is time and money consuming to eliminate the suspect factors by completing a series of tests. The recommended way is to establish a new approach that could help the design engineers capture knowledge from previous testing failures and successes to build a set of optimized rules in order to reduce the cost of the design changes.

3.7.1 EMC Design Issues

EMC Design Issues is developed as deign rules, i.e. the knowledge captured in past problem solving activities, that could provide a guide to EMC designers to ensure their design meet EMC requirements. It is supposed to be built on foundation of general EMC rules with supplemented by different customer's requirements if necessary, as shown in Figure 3.14:

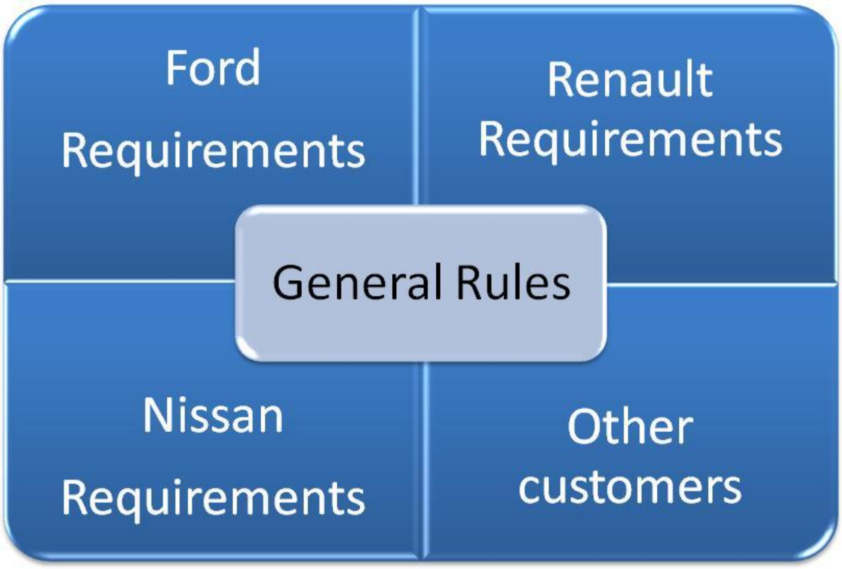


Figure 3. 14 EMC Design Issues

A classification of these design issues is described as follows (Tim, 2007):

(1) **Circuit design:** analogue bandwidth limitation, power segmentation and decoupling, choice of clock frequencies, clock distribution and buffering;

(2) **PCB layout:** 0V plane(s), power plane(s), layer stackup, decoupling placement, component placement, constant impedance layers, heatsink and mechanical aspects, general routing;

(3) **Interfaces:** power supply filtering, low frequency unscreened cable port filtering, high frequency unscreened cable port balance and common mode chokes, connection of screen to chassis for screened cable ports;

(4) **Enclosure design:** aperture size and location, bonding of structural parts, use of conductive gaskets, mating surface treatment and paint masking, PCB-to-enclosure connections, localized screening, moulding design for conductive coatings and choice of coating.

3.8 Research Gap

Through the literature review, it can be identified as following:

1) The problem solving process has been well identified, and developed with related

analysis tools;

2) Compared with other problem solving approaches that cover the whole problem solving process, A3 Thinking approach is simple but logical, content-structured, visualised, and compatible with these analysis tools, for solving design problems;
3) The applications of FMEA and A3 Thinking are well accepted;
4) There is no comprehensive mechanism which integrates FMEA and A3 Thinking templates as a whole that can identify problems, visual communication, and solve problems;
5) The integration could be used for knowledge capturing and provision at design stage in order to guide design engineers to improve design quality (refer to Research Question 1 & 2).

4. Industrial field study

4.1 Introduction

The aim of this chapter is to generally describe the current status of the product development process within EMC consideration of the collaborative company. The research initially focuses on the documents that could partly reflect the problem solving process of the company. Meanwhile, interviews with EMC design engineers are carried out using structured questionnaires and a prototype of integrated approach to get the feedback through expert's view. Finally, current limitations are identified based on the results of the document research and interview data.

The collaborating company is a 1st tier automotive supplier providing electrical parts and components. At present, the company faces a big number of EMC failures in new product development. Current attempts of generating the knowledge created in previous problems solving and providing for future use are not effective enough to decrease the EMC failures. The following sections will explain in detail.

Team Research

The research with the company is a part of the LeanPPD project with the 1st tier of supplier in the automotive industry, led by Dr. Ahmed Al-Ashaab & Mr. Maksimovic, Maksim, with members Mrs. Norhairin Mohd Saad, and the author. The aim is to develop an EMC knowledge model, following the Lean Knowledge Life Cycle (LeanKLC) methodology, which will be used to generate a SMART EMC checklist in order to provide the key lessons learnt in the early product design phases.

The main interactions with the collaborative company are as follows:

1. A visit to the EMC laboratory where EMC tests are performed;
2. Document research carried out with support from the company;

3. Interviews with 12 EMC design engineers using semi-structured questionnaire;
4. A series of progress meetings with EMC engineers held in the company;
5. Communications through E-mails, phones and online chart with WebEx.

4.2 Analysis of EMC Design Consideration within Current Product Development

The AS-IS workflow of this company has already been identified by the previous efforts of PhD. Student Mr. Maksimovic, as shown in Figure 4.1:

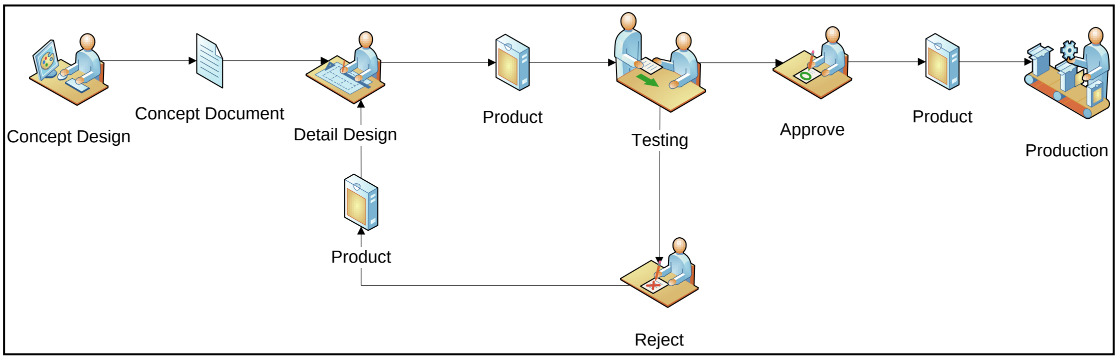


Figure 4. 1 The AS-IS Workflow Diagram (Maksimovic, 2011)

Once there is a new project, concept design and detail design will be performed progressively according to the specific customer requirements,. Then a physical prototype with related design verification test plan comes up. After the EMC validation testing, if the product is approved, it will be released to production; whilst if rejected, it will go back to detail design. Based on the failed testing result, the EMC application engineer, or a team will be assembled if necessary, to find out the causes of the failure, and carry out necessary corrective actions in the form of, for example, modification on the design, to ensure the product will pass the next validation testing.

4.2.1 The Current EMC Issue Documentation

The following documents are provided by the company as important information regarding previous EMC failures and their current status:

1) **First Time Through (FTT) Data Global Electrics**: a set of data which is to measure the ratio of the part or component passes the EMC validation and verification tests in the first time, related to companies in different area of the world.
2) **Issues Logging**: a document in Excel sheet, made by one of the EMC application engineers to record a number of previous EMC failures; only a few of them are completed.
3) **Round Table Senior Managers Discussion paper**: a document which shows that the company is taking actions to assemble a group to reduce the occurrence of the EMC failure, with current status described generally.
4) **VPRS Tracker**: a more formal document than Issues Logging, recording the failures in the past with their status.
5) **EMC Test Reports**: 24 EMC test reports, which are made by an EMC Test Technician.
6) **Problem Solving Report:** 3 reports are provided in different forms, related to 3 EMC failure issues.

In actual fact, according to the historical data of problem solving related to EMC testing failure provided by the company, it is indicated that:

a) According to the data in 'First Time Through (FTT) Data Global Electrics', from May 2010 to April 2011, nearly 200 products failed the EMC validation testing, but only a few of them were solved.
b) 'Issue Logging', 'VPRS Tracker' and 'Problem Solving Report' could be seen as three methods to document the important information of previous solved or unsolved problems. The differences are, 'Issue Logging' and 'Problem Solving Report' are done individually by some engineers without standard template, that increased the complexity of retrieving these information; whilst 'VPRS Tracker' is maintained company-wide to record the information in problem solving

activities using the ‘8 disciplines’ (8D) approach. The information regarding each failure, including the title of the failure, product type, root cause and prevent recurrence actions developed during the problem solving activities was documented in simple words, such as a log file. It is difficult to retrieve the valuable experience that was created in previous problem solving activities from such a kind of document.

c) ‘Round Table Senior Managers Discussion paper’ is a meeting log which shows the company introduced several actions designed to reduce recurrence of failures by setting up common rules and solutions based on historical data. But currently no standardized process is utilised, and the knowledge created is not well shared. Some of the engineers tried to document the problem solving activities they were involved in, but the structure of these issues varies, and the content needs to be customised.

4.2.2 Interviews with EMC Engineers using Semi-structured Questionnaire

The interviews are carried out with 12 EMC Application Engineers and Electrical Design Engineers, who are heavily involved in design activities with EMC consideration. Most of them have more than 10 years, or even 20 years experience on related work. The files of ‘Issue Logging’, ‘Problem Solving’ and ‘VPRS Tracker’ mentioned in last section are also mainly done by them. A semi-structured questionnaire is developed by PhD. students Mr. Maksimovic and Mrs. Norhairin Mohd Saad., including 5 sections: 1. Learning Cycle; 2. Failure Documentation; 3. Problem Solving Approach; 4. Methodology; 5. Additional Questions. The questionnaire covers the initiated failure documentation which was presented to the engineers. The author participated the interviews with 8 engineers, and collected the data, analysed the responses. Questions and feedback only related to the subject of the research are presented as follows.

Question 1: How do you assess the following Failure Documentation?

EMC Failure Documentation								
Part Name	Product Type	Test Failed	Area Failed	Root Cause Discipline	Risk Priority Number			
					Occurrence	Detection	Severity	RPN
T5 Cluster	Instrument Cluster	Electrostatic Discharge	Whole Component	Electrical	2	9	8	144

Figure 4. 2 Proposed Failure Documentation

Figure 4.2 shows the proposed failure documentation, which was presented in the interview. This failure documentation prototype is constructed based on the FMEA template. It will document the important information regarding each failure, including related part name, product type, failed test type, area failed, root cause discipline, and parameters for RPN.

The feedback is based on the answers of 12 questionnaires as follows:

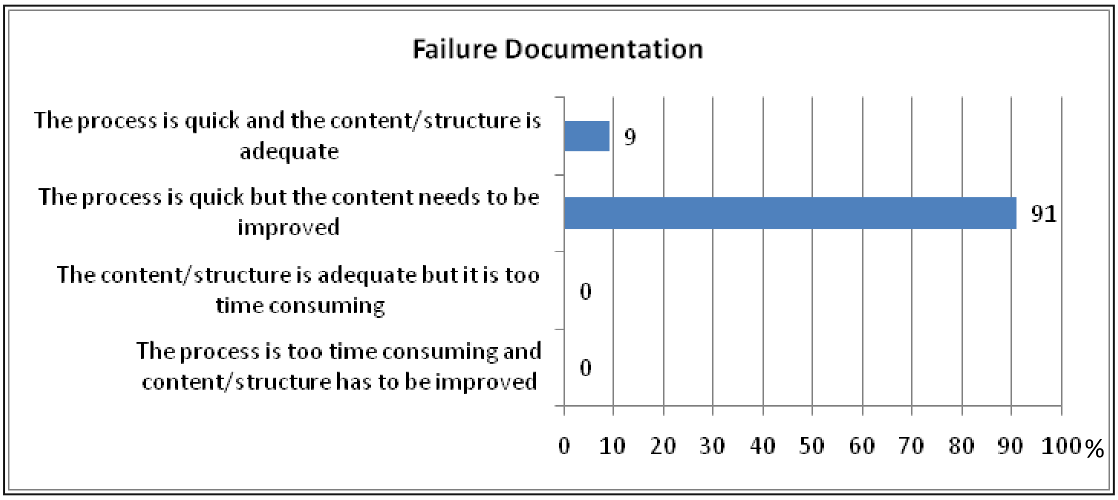


Figure 4. 3 Feedback of the Failure Documentation

From the results of questionnaire, most of the engineers agreed that the process of documentation and retrieval for EMC testing failure issue in Failure Documentation is time saving.

Question 2: How do you assess the importance of the following 5 elements in the

Failure Documentation?

Each element in the prototype is separated to allow its importance to be assessed when dealing with EMC issues through EMC Engineer's view.

1. Part Name and Product Type:

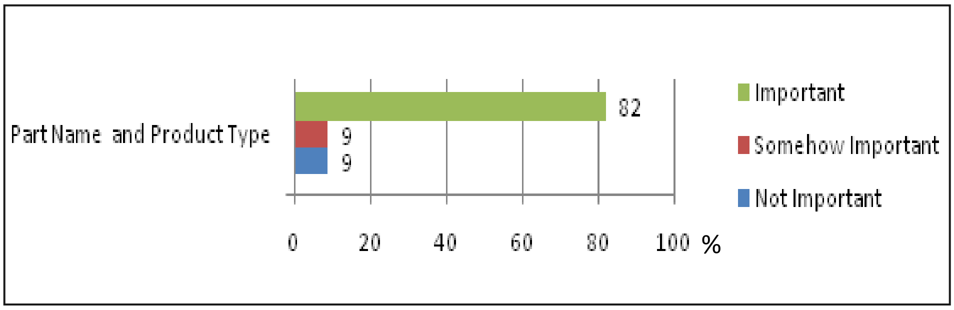


Figure 4. 4 Feedback of the content: Part Name and Product Type

Part Name and Product Type are important for engineers to trace the product. It is suggested to add Serial Number, Printed Circuit Board or Printed Wire Board Number and EMC Validation Report Number. The engineer also mentioned that once the Serial Number is selected, the other information could be automatically traced if a Product Lifecycle Management System exists.

2. Test Failed (which test type is not passed on the part/component):

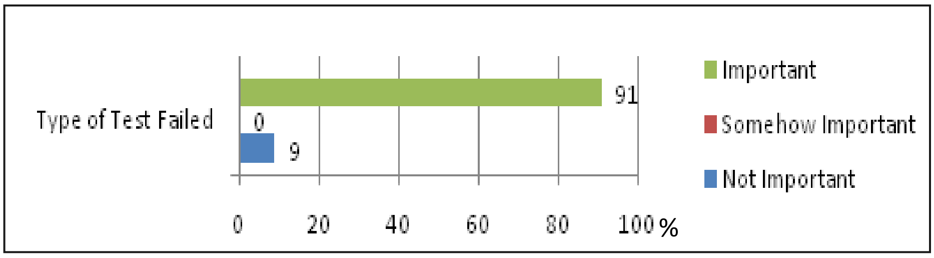


Figure 4. 5 Feedback of Content: Test Failed

The 'Test Failed' covers 5 EMC test types, including Radiated Emission (RE), Conducted Emission (CE), Conducted Immunity (CI), Radiated Immunity (RI), and

Electrostatic Discharge (ESD), which could refer to Section 3.6. It is mentioned by the engineer that the type of Test Failed could be expanded with information regarding the exact customer, related specification and its version.

3. Area Failed (The part/component is related to which area of the product):

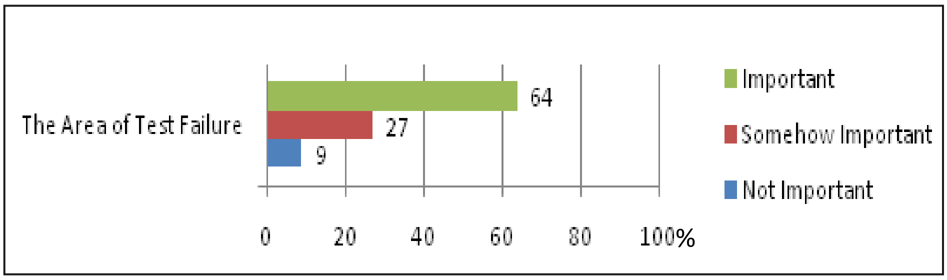


Figure 4. 6 Feedback of content: Area Failed

The engineer said that the content in Area Failed depends on the position of the person filling this box. It has to be customised as effect of failure or initial diagnosis, which could be a reference for problem solving.

4. Root Cause Discipline:

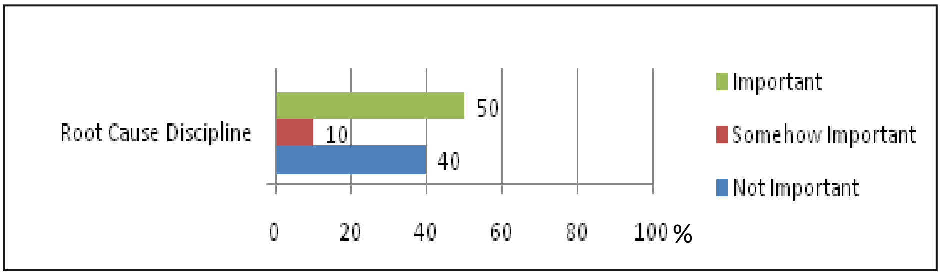


Figure 4. 7 Feedback of the Content: Root Cause Discipline

Comments from the engineer indicated that defining the Root Cause Discipline may cause jumping to conclusions and increase the risk of creating a blaming culture. The test technician may not be able to accurately determine the root cause discipline.

5. Risk Priority Number:

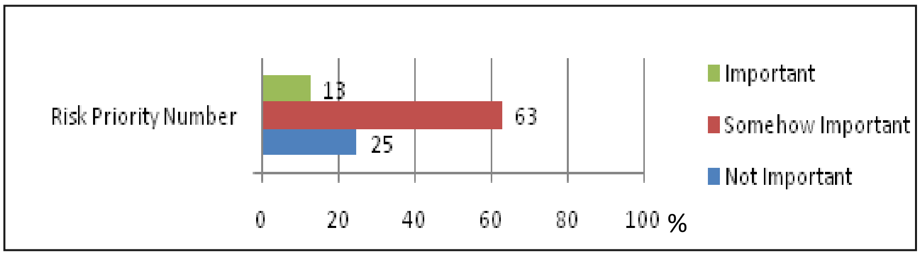


Figure 4. 8 Feedback of the Content: Risk Priority Number

The Risk Priority Number used in the prototype is a standard format from FMEA. However, it appeared not appropriate for the EMC testing. As the engineers said, the RPN should be specified for the specific EMC use. For example, Occurrence may be replaced by the number of the same failure that happened in the past; the functional level and type of test failed will indicate the severity of the test.

Question 3: Which of the following learning cycles have you formally implemented as a guide to continuous improvement in the company?

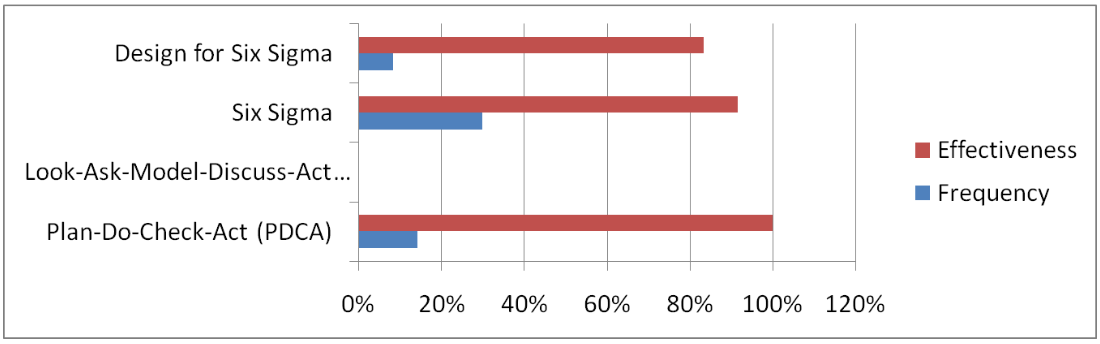


Figure 4. 9 Feedback of Learning Cycle implementation

According to the results, PDCA was agreed by the engineers as the most effective learning cycle when they implement it as a guide to achieve continuous improvement in their company.

Interview Result Analysis

After the interview with 12 of the company engineers, a general view was obtained concerning the knowledge capturing and reusing level of this company, as follows:

a) According to the results, most of the engineers acknowledged the knowledge creation during problem solving process, the necessity and importance of capturing and reusing the knowledge for making decision in the future.
b) Most of them thought the knowledge capture using a template in the company was at a ‘very poor’ or ‘fair’ level. Most of the time, the problem solving processes were performed by EMC engineers individually, not much active communication between them. The results were not well documented.
c) The observation indicated that the knowledge sharing in the company was usually limited in small group with only a few people, like small talks, passive interactions when facing failures, a few lessons learnt

Research Actions

According to the results of analysis on interviews response and files, the following actions are set to improve knowledge capturing, provision and sharing in the company:

1) Setting a process to capture and provide EMC knowledge throughout the product development process.
2) Defining and designing standard templates (Failure documentation, Pass-Test knowledge, A3 Thinking & SMART Checklist).
3) Capturing the link (inter-relation) between the templates to provide knowledge provision.
4) Knowledge provision
   --To solve design problem under consideration
   --To provide knowledge to new projects via SMART Checklist

Author’s contribution

The author’s contribution will be to develop the linkage between FMEA-based failure documentation and A3 Thinking templates in order to solve problems, capture the knowledge created in problem solving, and provide it to users in the form of checklists for future use, which could refer to the Action 2 (Failure Documentation and A3 Thinking) & 3.

5 Integration of Failure Documentation and A3 Thinking Development

5.1 Introduction

This chapter emphasizes the description of the integration development. Firstly, the To-Be scenarios of knowledge capturing and provision are presented. Then the proposal of the interrelationship between FMEA and A3 Thinking templates is described (refer to Figure 5.1). The process of application of the integration is interpreted. Finally, the concept is illustrated through case study.

5.2 Interrelationship between FMEA and A3 Thinking template

Basically, referring to Tables 3.6, 3.7 and Figure 3.12, the main elements in FMEA and A3 thinking templates could be summarized as follows:

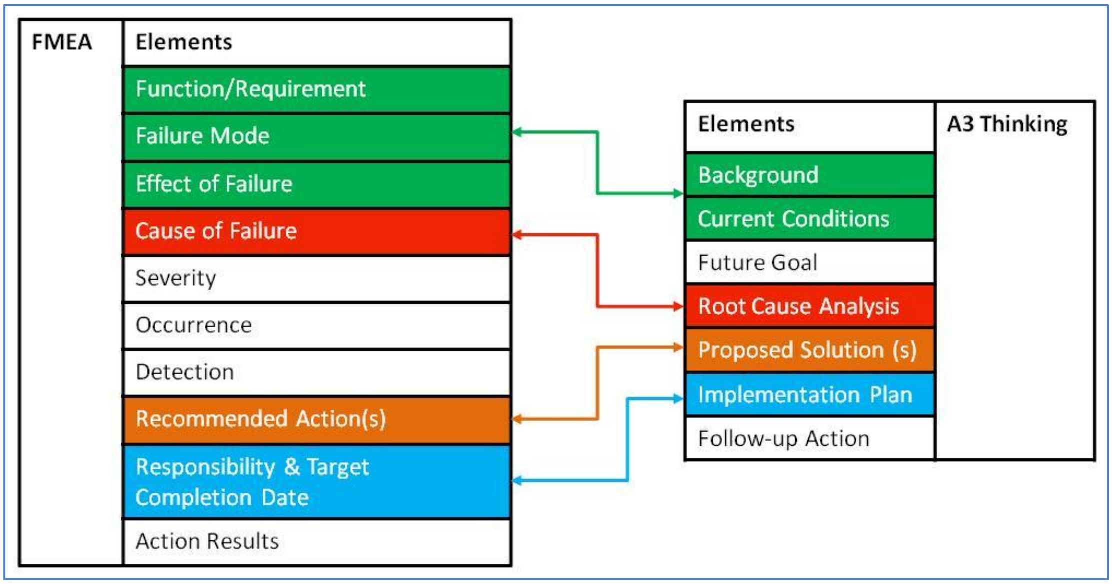


Figure 5. 1 Interrelationships between FMEA and A3 Thinking templates

Figure 5.1 shows the elements in FMEA and A3 Thinking templates:

FMEA template: shows Function/Requirement, Failure Mode, Effect of Failure, Cause of Failure, Severity, Occurrence, Detection, Recommended Action(s), Responsibility & Target Completion Date, and Action Results.

A3 Thinking template: shows Background, Current Conditions, Goal, Root Cause Analysis, Proposed Solution(s), Implementation Plan, and Follow-up Actions.

According to the definition of the elements in the two templates, a close relationship between FMEA and A3 Thinking templates could be identified.

For example, the contents of ‘Function/Requirement’, ‘Failure Mode’ and ‘Effect of Failure’ in FMEA (Refer to Section 3.5.2, p. 31) and the elements of ‘Background’ and ‘Current Condition’ in A3 Thinking template (Refer to Section 3.6.1, pp. 39-40) equally cover the information of ‘where is the failure’, ‘what is the failure?’, and ‘what is the effect?’ It means that when using FMEA to identify a new problem, the ‘Function/Requirement’, ‘Failure Mode’ and ‘Effect of Failure’ are analysed, these information could be transferred into the ‘Background’ and ‘Current Condition’ when using A3 Thinking template to help solve the problem without performing the same analysis on the failure again. The similar relationships occur between ‘Recommended Action(s)’ and ‘Proposed Solution(s)’, ‘Responsibility & Target Completion Date’ and ‘Implementation Plan’.

More importantly, FMEA and A3 Thinking templates both have their advantages during the process of problem identification and problem solving. FMEA could be applied to problem identification in a quick way. According to the successful application of FMEA, once the definition of the system, where FMEA will be applied, is established, it will be quick to go through the FMEA process to help identify the problem. It could be very efficient to go through the FMEA process when dealing with problems that are easy to solve. In addition, when more FMEA reports are documented after implementing it for long-term time, it will be helpful for static analysis. On the other hand, the A3 Thinking template provides more space for analysis of the problem, hence is recommended when managing more complex failures. Following the process of the A3 Thinking approach, it will be helpful to visualise the problem solving process, and communicate the solutions. Finally, each completed A3 report forms an easily-accepted way to present the knowledge that was created in problem solving.

Due to the complexity of EMC failure, most of them could not be identified in advance until the related tests fail, FMEA could not be used to effectively identify potential failures. But a FMEA-based Failure Documentation could be used to document the important information of EMC failure, and inform EMC application engineers what the failure is before performing problem solving using A3 Thinking approach.

5.3 Case Study of the Integration

5.3.1 To-Be Scenario of Knowledge Capturing and Provision

Based on the current AS-IS Workflow presented in Figure 4.1 (pp. 49), and the results of the document research (Refer to Section 4.2.1, pp.50-51) and interview with EMC engineers (Section 4.2.2, pp. 51-56), the To-Be scenario is stated by the team as shown in Figure 5.2. Currently in the company, failure reports are developed individually with different formats and not well maintained and shared company-wide, it is difficult to retrieving the information regarding a previous failure, which may be hidden in someone's documents. In that case, a standard format to document the EMC failure is required, and the documentation could be accessed by other engineers. In the To-Be scenario, Failure Documentation and A3 Thinking approach will be implemented to help solve the problem and capture the knowledge. The To-Be scenario of knowledge capturing can be divided into 6 steps.

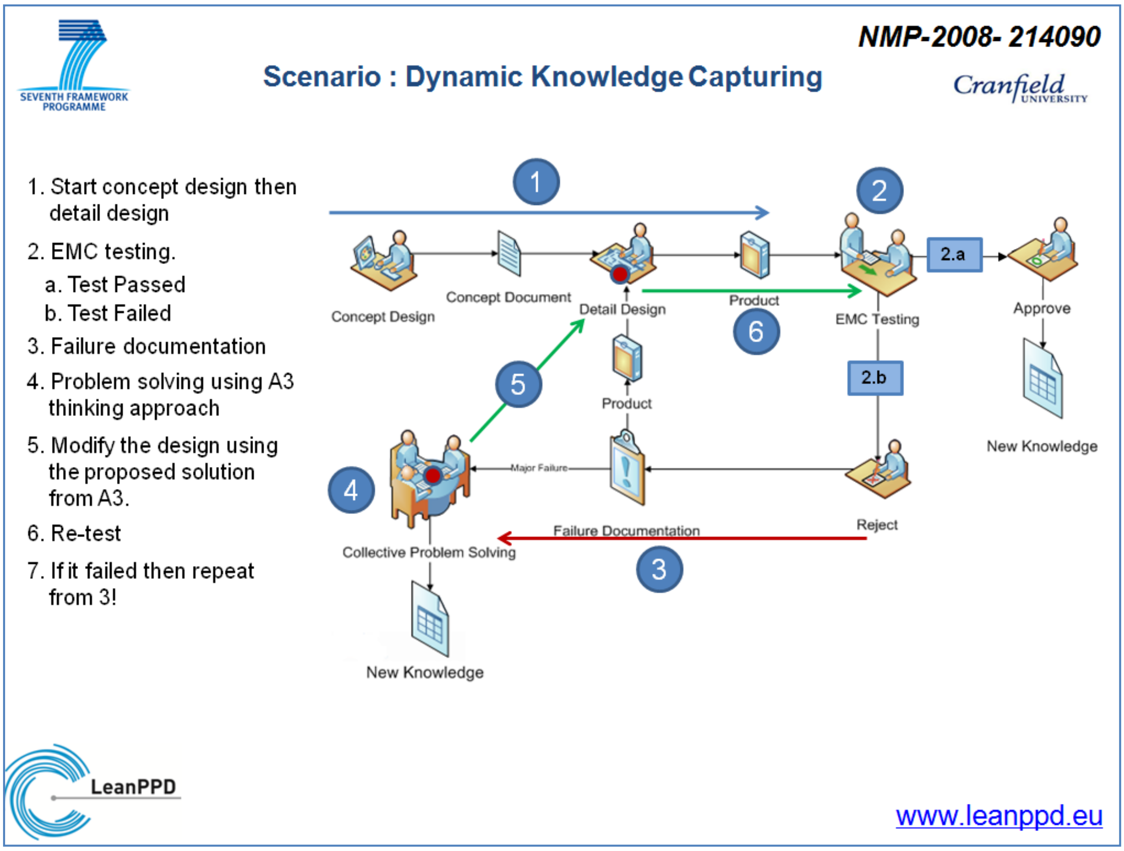


Figure 5. 2 The To-Be Scenario: Dynamic Knowledge Capturing (Maksimovic, 2011)

Step 1: Conceptual Design and Detail Design

In new product development, according to the requirements of the new product come from customers or market research, the identification of these requirements, product develop engineers perform conceptual design and detail design, and produce a physical prototype.

Step 2: EMC Testing

The prototype goes through required EMC tests (Refer to Section 3.7, pp. 43-45) to assess its electromagnetic compatibility. If it passes the test (2.a), the product model will be released to production. The configuration of the prototype will be documented if necessary, as it is likely to pass the EMC test. If it fails the test (2.b), it will be rejected.

Step 3: FMEA-based Failure Documentation

The failure in the EMC testing will be documented in FMEA-based Failure Documentation (refer to Section 5.3.5, p. 69). The responsible engineer(s) will be informed, and assemble a team if necessary, to prepare to solve the failure.

Step 4: Problem Solving using A3 Thinking approach

The engineer(s) will use the A3 Thinking approach to solve the failure, and document important information in A3 Thinking template (refer to Section 5.3.6, p. 75).

Step 5: Solution Implementation

As the practical solution is generated in the A3 thinking approach, a plan will be made to assign tasks to implement these solutions.

Step 6: Solution Effect Confirmation

Re-test the product when the solutions are implemented, to validate the effectiveness of solutions. If it fails again, then repeat from step 3 until finding the right solutions that will help the product pass the test.

Each failure will be documented in an A3 report with practical solutions, which is the knowledge that will be transferred into rules and questions with classification. After implementing Failure Documentation and A3 Thinking over a long term, a number of failures will be solved, a set of knowledge with checklist questions will be generated, a checklist with these questions will be provided to EMC design engineers when a new project comes up, which will help design engineers avoid repeating same failure, and then improve design quality.

5.3.2 Key activities in the EMC problem solving process

In order to help EMC engineers understand the role they will play in the key activities in the EMC failure documentation and problem solving process, a process flow chart with detailed activities is developed as shown in Figure 5.3, according to the information gathered during interactions with the company:

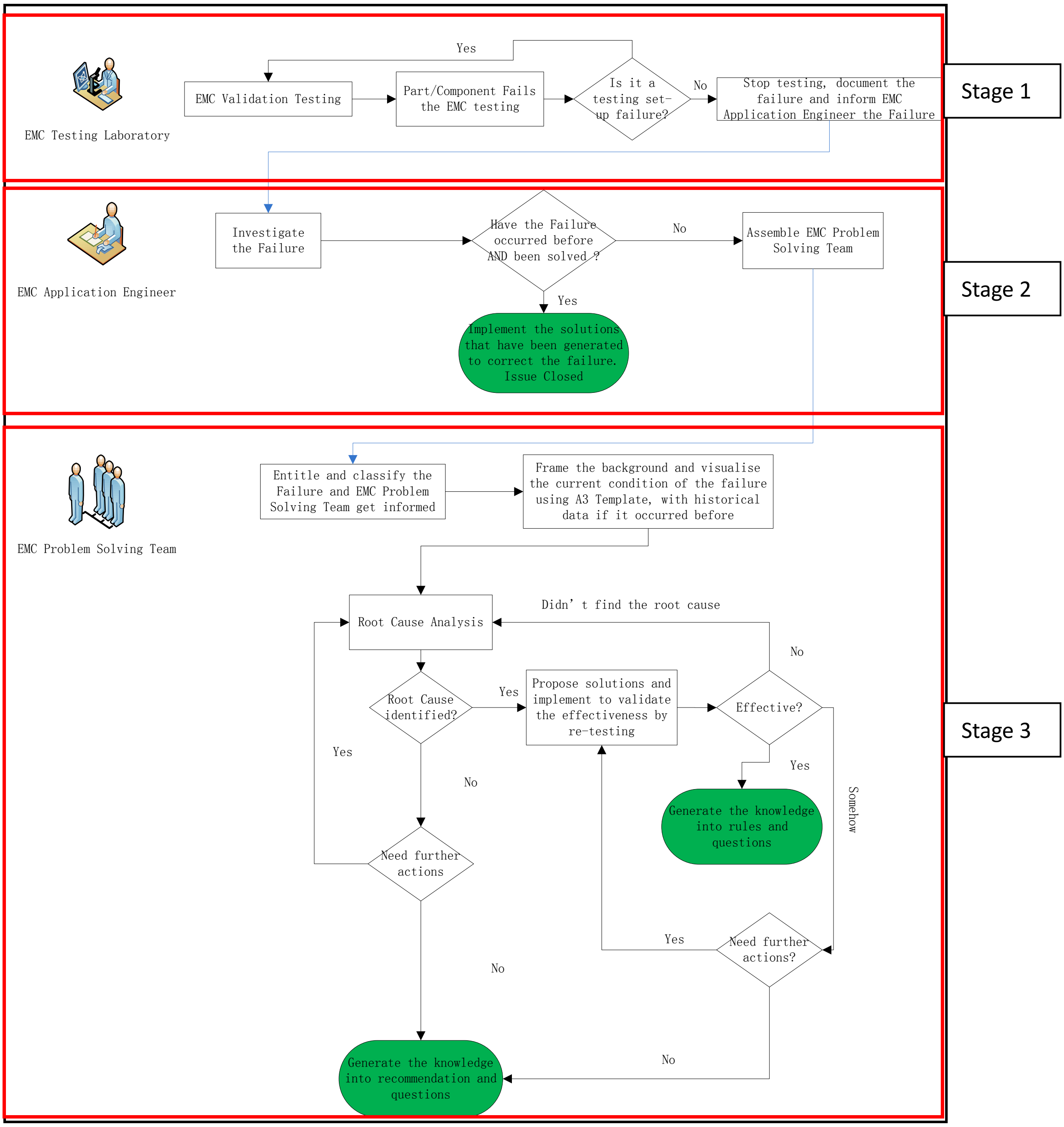


Figure 5. 3 EMC Problem Solving Process

STAGE 1: When the product fails EMC testing, then firstly the testing technician will confirm if it is a test set-up failure, which is not related to the topic. If not, the technician should immediately stop testing, use a failure documentation template to document the failure, and inform the responsible EMC application engineer.

STAGE 2: The EMC application engineer will initially investigate the failure, to consider its complexity, and decide the necessity of starting A3 thinking to solve the failure. If so, assemble a team when applicable.

STAGE 3: The EMC problem solving team follows the procedures of A3 thinking, initial the title, frame the background and current conditions, and perform root cause analysis. Once the root cause is identified, solutions will be proposed, and implemented.

If effective, the team will generate the knowledge regarding this issue into rules and questions to enrich the knowledge database.

If not effective, the team may need to reconsider the root cause, since the real root cause may still hide.

If somehow effective, the team may need to consider updating the solutions.

In reality, due to other factors of the project, resource constraints limit performance of further actions. Therefore the team is responsible for summarising all the knowledge created in the process, and making recommendations for future use.

5.3.4 Interrelationship between EMC failure and EMC Design Issues

This section presents the linkage between solved EMC failure and EMC knowledge, which is in from of EMC Design Issues and questions. The relationship between specific EMC failure and related EMC design issue could be established through problem solving and knowledge capturing as follows:

EMC Failure		**EMC Related Disciplines**		**EMC Design Issues**
Customer	➡	Electrical	➡	Circuit design
Part/Component		Software		PCB Layout
Specifications		Mechanical		Interfaces
EMC Test Type		+More		Enclosure design

Table 5. 1 Interrelationship between EMC Failure, EMC Disciplines and EMC design issues

1) EMC Failure to EMC Related Disciplines.

When a failure occurs, according to the information available, which include customer, part/component, related specifications and specific EMC test type. Through problem solving, we understand the cause and effect of the failure, and carry out the solutions, while the failure will be linked to related EMC disciplines.

2) EMC failure to EMC Design Issues.

After the failure is solved, the knowledge is created based on the results of cause analysis and effective solutions. The knowledge is documented in Failure Documentation and related A3 reports. After that it could be transferred into EMC Design Issue and checklist question. The knowledge will be accumulated after implementing this process over a long-term. Figure 5.4 shows 6 classes of EMC questions related to Components and circuits, Printed Circuit Board (PCB) Layout, Cables, Grounding, Filters, and Shielding, generated from EMC design issues mentioned in Section 3.7.1. The relationship between EMC Design Issues and EMC Questions examples is also presented in Figure 5.4:

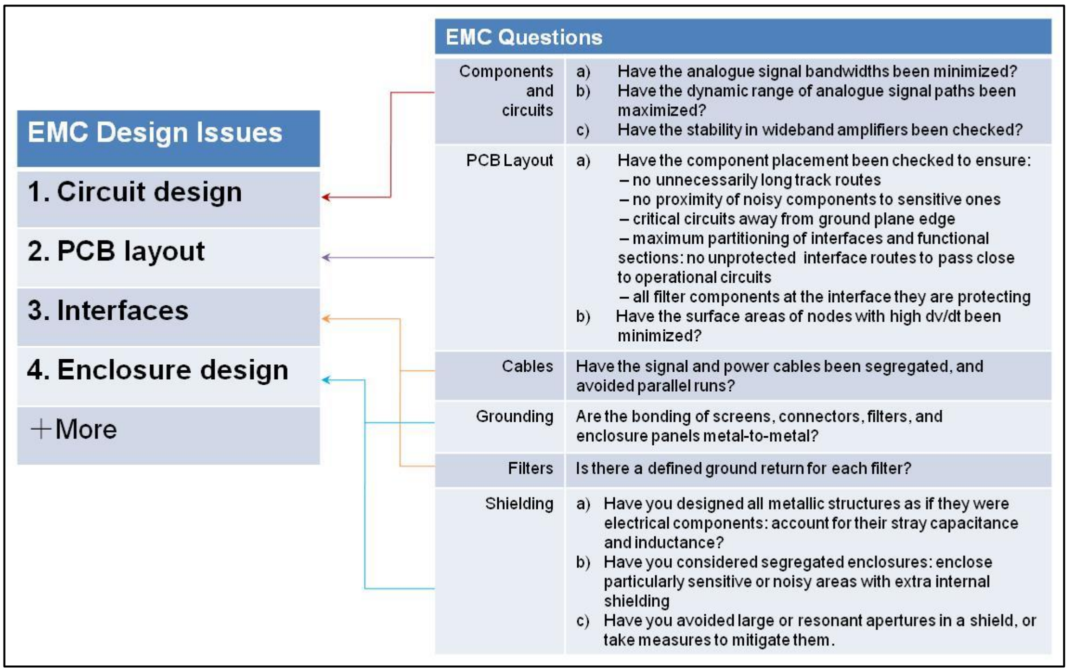


Figure 5. 4 EMC Design Issues and EMC Questions

Each question will be linked to a particular A3 report, in which the EMC failure was solved, and the knowledge was generated, in order to provide more information to engineers when required. These questions will be provided to EMC design engineers in the form of a checklist to help avoid recurrence of EMC failures, when carrying out a new project.

5.3.5 EMC Failure Documentation

In this research, the author carried out a case study with the collaborative company on a real failure happened. An audio part failed the EMC Radiated Emission test, which was required in the test plan. It was indicated in the testing report that the part was transmitting at about 1.002 MHz.

The Failure Documentation is developed based on FMEA template, covering key elements of Function, Failure Mode, Effect of Failure, and Priority Risk Number. The content of each element is modified for EMC issues.

Function

As the EMC test type structure has already been made with the specific customer, and to suit the application of failure documentation, the function is defined as the part or component which will go through the required EMC testing. In the case study, to detail a particular unit under test, it will include Product Type, Product Name, Product Code, Software No., Printed Circuit Board No. and Serial Number. These elements are with consideration of the feedback from EMC engineers during interviews and exercises.

Failure Mode

Failure Mode is the way that the unit fail the tests. It would be that the unit may not meet a particular requirement of test. The unit made for different customers will bring various requirements, or even for just one customer, the requirements will differ because the products may be released to different world markets, then relevant government regulations could be added into considerations when designing the unit. The Failure Mode in Failure Documentation will include Test Request Number (The unique number for tracking every test) and Test Type.

Effect of Failure

During the EMC testing, when a failure occurs, testing engineers will document the observations with professional descriptions (in words and diagrams), and that will be the content of 'Description of the Failure' in Failure Documentation.

Priority Risk Number

3 parameters for risk assessment method are also developed in Failure Documentation, according to customers' requirements. They are Functional Status, Functional Performance Class, and Occurrence.

Functional Status**:** to define the importance of the unit with respect to safety in vehicle operation. Different customer will have different definition on functional status. For example, in Renault's specification, the importance of the unit is defined in five classes, while in Ford's, there are only three classes. Followings are the definition of these classes from Renault (Renault, 2009):

Class A**:** All functions of a device/system perform as designed during and after exposure to disturbance.

Class B**:** All functions of a device/system perform as designed during exposure. However, one or more of them can go beyond specified tolerance. All functions return automatically to within normal limits after exposure is removed. Memory functions shall remain class A.

Class C**:** One or more functions do not perform as designed during exposure but return automatically to normal operation after exposure is removed. During exposure, Equipment Under Test (EUT) shall not operate unexpectedly.

Class D**:** One or more functions of a device/system do not perform as designed during exposure and does not return to normal operation until exposure is removed and the device system is reset by simple "operator/use" action.

Class E**:** One or more functions of a device/system do not perform as designed during and after exposure and cannot be returned to proper operation without repairing or replacing the device/system.

Functional Performance Class: It is the performance of the unit under test, when subjected to a disturbance. The types of these undesirable effects are also defined in customer's specifications. Table 5.2 shows the functional performance class from Ford (Ford, 2010)

Level	**Definitions**
I	The function shall operate as designed (or meet specified limits) during and after exposure to a disturbance
II	The function may deviate from designed performance, to a specified level, during exposure to a disturbance but shall not affect safe operation of the vehicle, safety of its occupants and does not adversely affect customer satisfaction. The function may revert to a fail-safe mode of operation, but shall return to normal

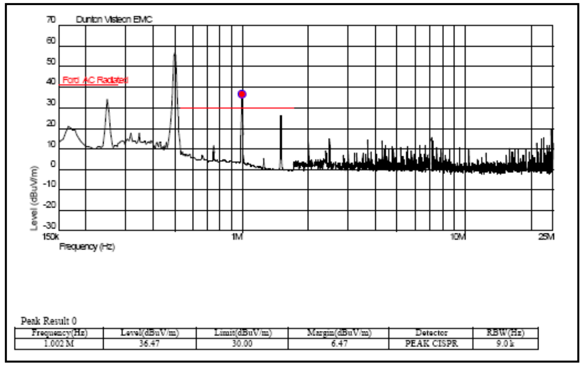
	operation following removal of the disturbance either automatically or in line with the function's fail-safe recovery strategy. No effect on permanent or temporary memory is allowed. Status II performance, where applicable, is only permissible if the deviation in performance does not affect other related functions requiring Status I performance.
III	The function may deviate from designed performance during exposure to a disturbance but shall not affect safe operation of the vehicle or safety of its occupants. Operator action may be required to return the function to normal after the disturbance is removed (e.g. cycle ignition key, replace fuse). No effect on permanent type memory is allowed. Status III performance, where applicable, is only permissible if the deviation in performance does not affect other related functions requiring Status I performance.
IV	The device shall not sustain damage, changes in Input/Output parametric values (resistance, capacitance, leakage current etc.) or a permanent reduction in functionality.

Table 5. 2 Definition of Functional Performance Class (Ford, 2010)

Occurrence: The times that failure recorded as happened. Occurrence is a parameter which will help to decide if high level actions are needed for frequent failures, and how effective of the solutions for previous failures.

The Failure Documentation has two forms, Input and List interfaces. The Input of Failure Documentation is developed for inputting information of new EMC failure to the required elements. List of Failure Documentation will document all the failures happened and solved before. It can have a search function that could help EMC engineers find out if the failures had previously occurred by class: Customer Specification, Product Type, Product Name, Software No., PCB No., and Test Type. In addition, when engineers input a new failure, and if the Customer Specification, AND Product Type, AND PCB No., AND Test Type of the failure match with that of any failures that had happened before, the List of Failure Documentation would directly filter out these failures, with linkage to related A3 reports in which practical solutions ware developed, and could be provided to engineers to immediately solve the failure. Then the Occurrence of the failure will count up one more time. This function could be realised when applying the Failure Documentation into a software.

The example of audio radiated emissions failure is stated in Failure Documentation as shown in Tables 5.3, 5.4 (The data filled in the templates is modified for confidential of the collaborative company):

<table>
<tr><td colspan="6">Input of Failure Documentation</td></tr>
<tr><td colspan="6">Title: The Audio radiated emissions failure</td></tr>
<tr><th colspan="2">Function</th><th colspan="2">Failure Mode</th><th colspan="2">Risk priority Number</th></tr>
<tr><td>Product Type</td><td>Audio</td><td>Test Type</td><td>Radiated Emission 01</td><td>*Functional Status</td><td>N/A</td></tr>
<tr><td>Product Name</td><td>Class D DAB</td><td>Customer Spec.</td><td>ES-XxxT 1xxx8 AC</td><td>*Functional Performance Class
**(Gravit Level)</td><td>N/A</td></tr>
<tr><td>Product Code</td><td>VPxxxF-18xxx9-DC/Cxx6</td><td>Test Request No.</td><td>EL10.0xxx9</td><td>Occurrence</td><td>1</td></tr>
<tr><td>Software Number</td><td>BxxT-14xx44-NCxx0</td><td rowspan="3">Other Information</td><td rowspan="3">N/A</td><td colspan="2" rowspan="3">*: “Functional Status” and “Functional Performance Class” are for Immunity tests only.
**: “Gravity Level” is for Renault only.</td></tr>
<tr><td>Serial. No. (S/N)</td><td>Z000325</td></tr>
<tr><td>Printed Circuit Board No.</td><td>17xx1</td></tr>
<tr><td colspan="3">Description of failure:
The peak marked in the diagram include information as follows:
Frequency: 1.002 MHz
Level: 36.47 dBuV/m
Limit: 30.00 dBuV/m
Margin: 6.47 dBuV/m</td><td colspan="2"></td><td>Figure 01: Radiated Emission 01 Test failure for Class D DAB</td></tr>
</table>

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

Table 5. 3 Class D DAB Audio Radiated Emission Failure

List of Failure Documentation							
No.	Customer Spec.	Product Type	Product Name	Software No.	PCB No.	Test Type	Occurrence
001	ES-XxxT 1xxx8 AC	Audio	Class D DAB	BxxT-14xx44-NCxx0	17xx1	Radiated Emission 01	1
002							
003							
004							
005							
006							
007							
008							
009							
010							
011							
012							
013							
014							
015							
...	......	......	......			......	......

Table 5. 4 Class D DAB Audio Radiated Emissions Failure in List of Failure Documentation

5.3.6 EMC Failure in A3 Report

As stated in Section 3.6, the A3 Thinking template provides a simple, visual and logical method to guide engineers in solving problems, and documenting the process. A modified A3 Thinking template is developed for this EMC issue case study. The element of 'Future Goal' is cancelled due to the main objective of solving each failure being to make the part or component pass the EMC validation testing, which is not necessarily existing in this A3 report. There are 6 elements with detailed description of the content in the modified A3 Thinking template:

1. Background	• EMC Testing Report, OEM, Part/Component Name, Failed Test Type. *To identify the functions.*
2. Current Conditions	• Description of the failure by using technical words from the report. *To state the effects of the failure.*
3. Root Cause Analysis	• To find out the causes of the failure, help make effective countermeasures. Using words, graphs, tables to visualise the process.
4. Proposed Solutions	• According to the root causes, propose solution to correct the failure.
5. Implementation Plan	• Make an action plan including the person responsible, tasks, datelines and deliverables.
6. Follow-up Action	• Check other similar designs and make conclusion to help avoid recurrence of the failure.

Table 5. 5 Modified A3 Thinking template for EMC case study

The content of each element in this A3 Thinking template is as follows:

1) Background. Related information of unit under test, including Product Type, Product Name, Product Code, Software Number, Serial Number, Customer Specification, and Printed Circuit Board Number. When the failure happened in the past and was not solved, relevant information can be included in this element.
2) Current Conditions. To state what is observed during the testing, including Test Request Number, Test Type, and Risk Priority Number from Failure

Documentation, and other detailed testing information, for example, frequency band, and how much did the result exceeded the limitation. It is suggested that fuzzy words, like ‘low’, ‘high’, ‘close’, may not be used. No further cause analysis is needed at this stage.

3) Root Cause Analysis. In this element, users could present the process of root cause analysis they have made. It is also suggested using Fish-bone Diagram, 5 whys, or other techniques to help find the root cause. Each cause identified will need objective evidence to confirm the rationality in the analysis if available. In this case study, the Fish-bone diagram is introduced with modifications to fit the EMC issues.
4) Proposed Solutions. The solutions should be made according to the causes identified. The EMC Problem Solving team could generate all the possible solutions at first, and then filter them for the final solutions.
5) Implementation Plan. The plan will state responsibility with each task, action date and deliverables. The result of the solution implemented will also be presented in this element.
6) Follow-up Actions: Generate the knowledge created in the process. According to the findings in this failure, to check whether there is any other similar potential failure may happen in other designs, in order to avoid recurrence.

As mentioned in Section 5.2, the information generated in Failure Documentation (refer to Section 5.3.5, p.71) could be directly transferred into an A3 report as a part of ‘Background’ and ‘Current Conditions’. After adding the other information required in ‘Background’ and ‘Current Conditions’, EMC engineers could start A3 Thinking approach with ‘Root Cause Analysis’, as showing in Figure 5.5.

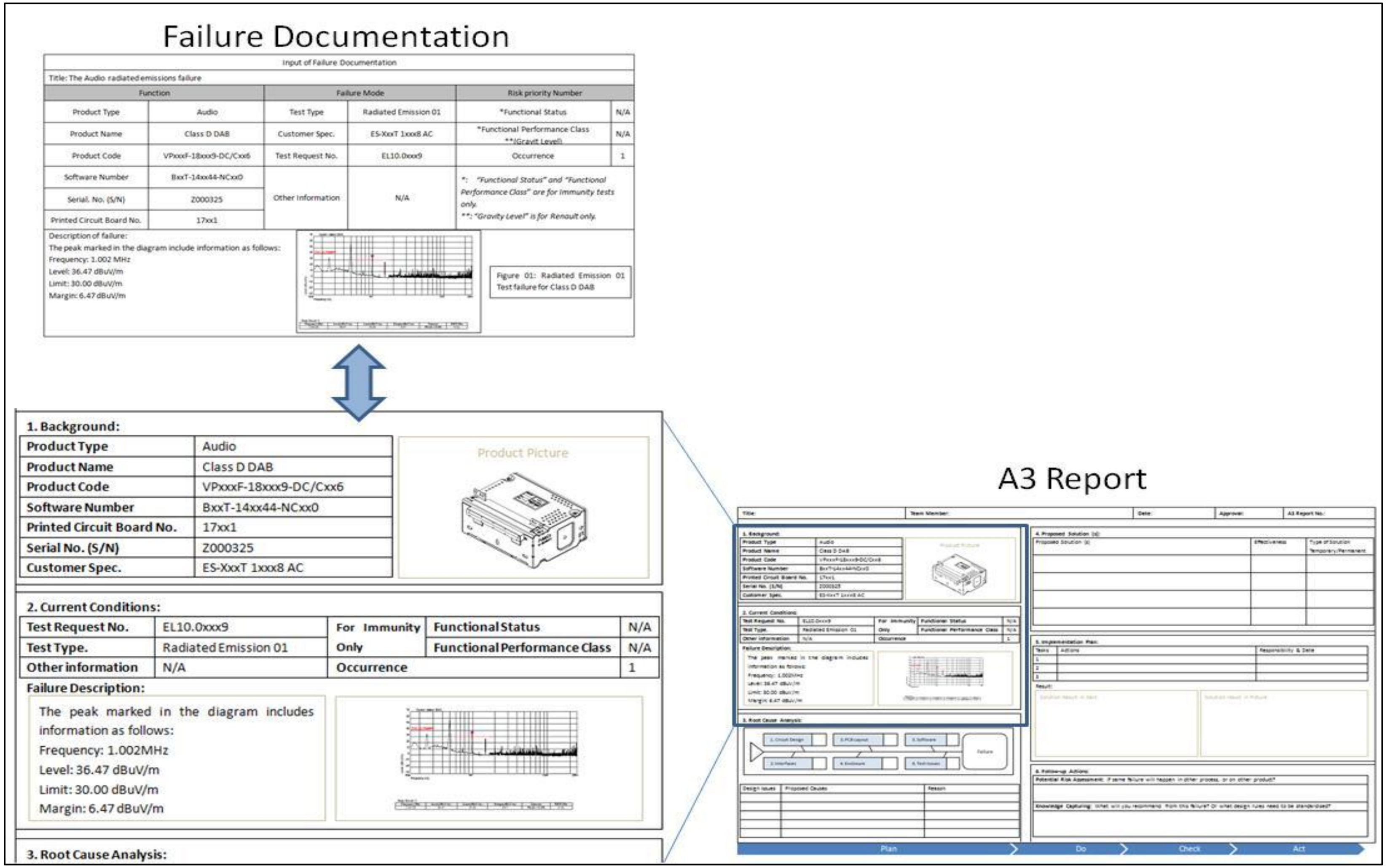


Figure 5. 5 Information transfer between Failure Documentation and A3 Thinking Template within Audio Radiated Emission Failure

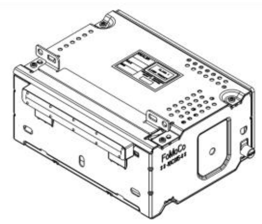
During the root cause analysis, EMC engineers proposed several causes based on their expertise and experience, then went through several experiments and reviewed the layout of the Class D DAB, finally found the root cause was the incorrect Class D output filter, and confirmed by frequency change in the experiment. They proposed a modification of the design to change the schematic and Bill of Material (BOM). Development testing and formal testing were also carried out to verify no side effect was made by this change. The result of confirmation test indicated no radiated emission exceeded the requirements any more. In the next step "Follow-up Actions", EMC engineers assessed if there would be any other similar failure happen on other product or process, and finally generate the knowledge. As Table 5.6 shows, at the end of A3 Report, it guides the engineer to formulate the EMC knowledge created in this problem solving, which is suggested to write into EMC Design issues, and be shared with other engineers.

Title: Class D DAB Audio Radiated Emission Failure	**Team Member:** Mark, Simon, Amin, Karl	**Date:** 12th Jan, 2011	**Approval:** John	**A3 Report No.:** 00001

1. Background:

Product Type	Audio
Product Name	Class D DAB
Product Code	VPxxxF-18xxx9-DC/Cxx6
Software Number	BxxT-14xx44-NCxx0
Printed Circuit Board No.	17xx1
Serial No. (S/N)	Z000325
Customer Spec.	ES-XxxT 1xxx8 AC

Product Picture

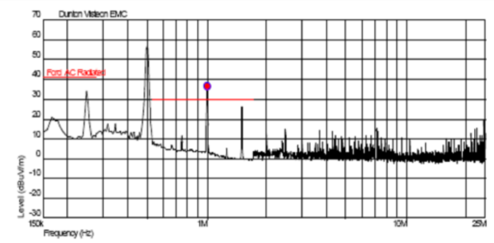


2. Current Conditions:

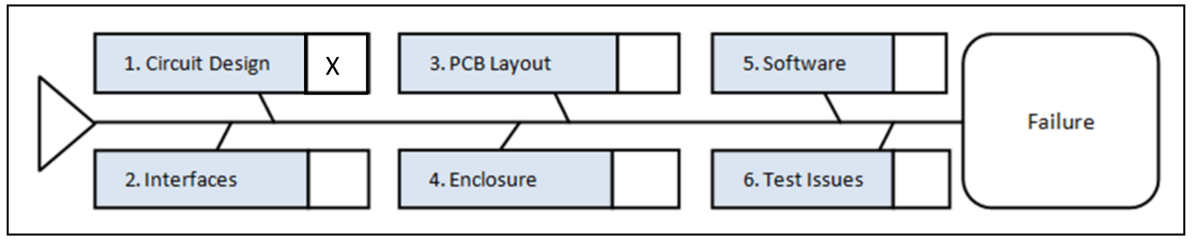
Test Request No.	EL10.0xxx9	**For Immunity Only**	**Functional Status**	N/A
Test Type.	Radiated Emission 01		**Functional Performance Class**	N/A
Other information	N/A	**Occurrence**		1

Failure Description:

The peak marked in the diagram includes information as follows:
Frequency: 1.002MHz
Level: 36.47 dBuV/m
Limit: 30.00 dBuV/m
Margin: 6.47 dBuV/m



3. Root Cause Analysis:



Design Issues	Proposed Causes	Reason to propose
Interfaces	Incorrect spectrum on speaker cable	Experience on previous failures
	Problem on power supply	Experience on previous failures
Circuit Design	Problem on Class D amplifier **(Root Cause)**	Experience on previous failures

4. Proposed Solution (s):

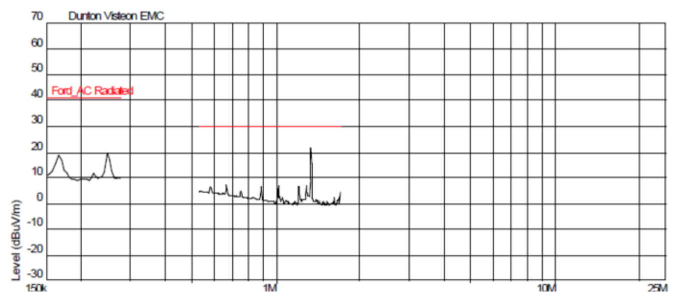
Proposed Solution (s)	Effectiveness	Type of Solution Temporary/Permanent
Spread spectrum on clock---(Proposed cause: Incorrect spectrum on speaker cable)	Not	Temporary
Changes to power supply filter---(Proposed cause: Problem on power supply)	Not	Temporary
Change to Class-D output filters (C2152, C2153 to 1uF)---(Proposed cause: Problem on Class D output filter)	Yes	Permanent

5. Implementation Plan:

Tasks	Actions	Responsibility & Date
1	Update design: change schematic, Bill of Material (BOM)	Charles, by 1st Feb., 2011
2	Verify changes: Development testing	Mark, by 5th, Feb. 2011
3	Formal testing: Management of Change, raise new test request, update samples	Roy, 5th, Mar. 2011

Result:

Retest on Radiated Emission 01, no failure exists as shown in the figure.



6. Follow-up Actions:

Potential Risk Assessment: If same failure will happen in other process, or on other product?

The solution is a simple change, zero on cost, low risk.

Knowledge Capturing: What will you recommend from this failure? Or what design rules need to be standardised?

Circuit Design: Recommendation 1, Class-D output Low Pass filter should have low enough cut-off to reduce amplitude of switching frequency and harmonics.

Recommendation 2, Testing needs to ensure that all outputs are fully exercised.

Plan → Do → Check → Act

Table 5. 6 Class D DAB Audio Radiated Emission Failure in A3 report

5.4 Evaluation of the Integration

The section presents the evaluation of the proposed integration between the Failure document and the A3 Thinking templates presented in section 5.3.5 and 5.3.6. It is based on case studies and the expert opinions of EMC Electrical Engineers, Product Assurance Engineer and Continuous Improvement Engineer in the collaborative company.

5.4.1 Evaluation Process of the Integration

The following process has been used to evaluate the research work presented in this thesis:

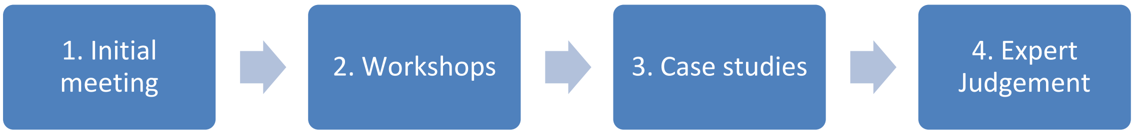


Table 5. 7 Evaluation Process of the integration

1. The research outline as well as the aim and objectives have been confirmed with the collaborative company in the initial meetings with different engineers;
2. The approach was proposed with FMEA and A3 Thinking templates in the workshops. According to the feedback from the engineers, it resulted into changing the name from FMEA to Failure Documentation;
3. Data collection for case studies. Four EMC failures have been selected to go through this proposed integration to assess the effectiveness of the approach. Engineers are involved to use the integration to solve EMC failures, and document into the templates. The purpose is to help EMC engineers fully understand the process of using the Failure Documentation and A3 Thinking templates by practice with the existing EMC failures. The interactions with the engineers helped the

author to modify and customise the templates to well fit in addressing the EMC issues within the collaborative company. However, due to confidential reason, only one case study has been reported in this thesis (Refer to Section 5.3.5, 5.3.6).

4. Expert judgement opinion for evaluating the results of the case studies. This is presented in following sub-section.

5.4.2 Evaluation Results

During the evaluation, three EMC Electrical Engineers, one Product Assurance Engineer and one Continuous Improvement Engineer were involved, with valuable comments on the integration. The feedbacks from engineers are summarised into positive comments and improvement opportunities as follows:

Positive comments:

During the evaluation, all the engineers agreed with:

1. It is obviously necessary to set an approach with standardised templates to document the solved failures with effective solutions, which is the knowledge.
2. It is believed that this integration with its procedures and templates could support effectively capturing the EMC design knowledge.
3. Through the exercises of using the templates to document the current EMC failures, it is indicated that the templates are easy to use. The elements in A3 template cover the whole problem solving process, and document a lot of important information that could help retrieve the failure.
4. The content in the templates is logical, concise and visual, explicit to understand. It is good to see all the information being summarised in this A3-size template. The categorisation in the templates is very important for knowledge capturing and documentation, for example, the categorisation of root causes.
5. The EMC Design Issues, where the knowledge will be finally stored, are well accepted by EMC Application Engineers, and the knowledge generated will

obviously help avoid recurrence of failures.

Improve opportunities:

EMC Electrical Engineers suggested that:

1. The consequence of the elements in Failure Documentation could be modified, with an addition of some other elements to require more information on the failure, in order to well fit the case study of EMC issues;
2. During the exercises, because of the restriction of the size of A3 Thinking template, it may not have enough space for some problem solving. It is suggested to have a bigger version or extend it with attachments, if necessary, or have a function that it could link other files into this A3 report.

Product Assurance Engineer stated that:

1. It is very good about one of the ideal presentation behind A3 report, that people could communicate it in a sharing environment.
2. The categorisation of root cause analysis, solutions and knowledge could be developed with consideration on the design process, not just design issues. It may have more effective use.
3. The parameters used in Risk Priority Number should have more concern with different situation, to have effective risk assessment.

Continuous Improvement Engineer said that:

This is an improved A3 Thinking template for specific use of solving and documenting EMC failures. The visualisation of A3 report is very good and important to this integration. However, the way to use this integration should be easy and convenient; otherwise people will not be able to be activated to use it.

6. Discussions, Conclusions and Future Work

This chapter will discuss the research work and achievements that have been completed according to the research aim and objectives, research methodology. In addition, the contribution to knowledge, research limitations, and future work recommendations are also described in this chapter.

6.1 Discussion

This research aims to provide integration between FMEA-based Failure Documentation and the A3 Thinking template for problem solving in order to realise knowledge capturing and provision at the design stage. The design quality could be enhanced by dynamic knowledge capturing and provision in order to guide the engineer to find practical solutions to solve current failures and avoid recurrence. The objectives carried out to achieve this aim are stated in Section 1.1.2 (pp. 3).

The research methodology structures the process which effectively guide author to carry on the research step by step.

1. Literature Review

The literature review helped author build the base theory of Knowledge Management, Knowledge Life Cycle, Problem Solving Process, FMEA and A3 Thinking approach. Through the literature review, the author synthesise the good practice of Problem Solving Process, FMEA and A3 Thinking. (Refer to Objective 1, pp. 3)

2. Industrial Field Study

During the industrial field study, the interviews with semi-structured questionnaire were performed. The feedback and result of analysis on the current EMC issues documentation was collected. The current work flow of solving EMC problems and documentation were quickly identified, in order to find the current limitations.

3. Integration Development

The interrelationships between the elements of FMEA and A3 Thinking templates were identified (Refer to Objective 2, pp. 3). With the To-Be scenario for knowledge capturing and provision in the integrated template, a case study was carried out to validate the integration, which is in purpose of guide users to solve the problem, document it in a standardised template. The integration could also be used in other situation, with specified content (Refer to Objective 3, pp. 3).

4. Evaluation

Finally, the integration was evaluated through experts' view from the company. Positive comments and improvement opportunities are presented in Section 5.4.2 (pp. 77-78). (Refer to Objective 4, pp. 3)

6.2 Conclusions

According to the research work and achievements, research conclusions could be made as follows:

1. During product development, design quality will be enhanced by solving design problems and avoiding recurrence. However, that requires knowledge for specific design process and activities.
2. Approaches used in problem solving are well accepted, but the integration among them to accelerate the problem solving process, improve the effectiveness, is not well established. This research focuses on the integration of FMEA and A3 Thinking templates, in order to solve problems in design stage.
3. During problem solving, people will create knowledge, the knowledge could be shared with others to avoid same problem. However, the way to document knowledge and provide it, will impact the effectiveness of the knowledge.
4. Knowledge needs to be captured, transferred into explicit form, classified, and well presented;
5. Failure Mode and Effect Analysis is widely used as an effective approach to identify potential problems and systematically perform risk assessment. A3

Thinking is developed by Toyota, as a visual communicating approach for problem solving and documentation. The new integration (Failure Documentation and A3 Thinking) with standardised template has been proven as followings:

a) Quickly define the problem using Failure Documentation;
b) Find the solution and solve the problem in A3 report;
c) Simply, logically and visually document the problem solving process;
d) Capture the knowledge created;
e) And provide it to engineers for future use---avoiding recurrence, in order to improve design quality.

6. However, the effectiveness of the knowledge would partly depend on the expertise of the engineer who fills in the content. Be careful of the reliability of the knowledge. Make sure the knowledge would be understandable, and have consistence within different engineers.

Contribution to knowledge

The research contribution is the integration of Failure Documentation and A3 Thinking templates, which will help users achieve knowledge capturing in design problem solving, provide it for future use, then improve design quality.

Research Limitations

1) This research was carried out with a case study in the collaborative company. It may need more case studies to validate the use;
2) Because the research time is limited, the integration has not been implemented for a long term, the effect of knowledge capturing and provision is not obvious;
3) The integration templates are working in Microsoft-Word, the interface is still not perfect. It may not be able to effectively activate people to use this integration without a user-friendly interface and efficient process.

6.3 Recommendations to Future Work

Some future work is recommended as follows:

a) Identify more critical factors of effectively implementing Failure Documentation and A3 Thinking approach in problem solving;

b) For EMC issues, add more detail elements in the integration templates with regards on different situations, that will enhance the effectiveness of the integration for different uses;

c) Develop data system and interfaces in software, to make the integration easy to use, for example, have the function that could keep big pictures and attach other related files, that will effectively encourage people to use it;

d) Accumulate the experience of using the integration, and continuously improve it.

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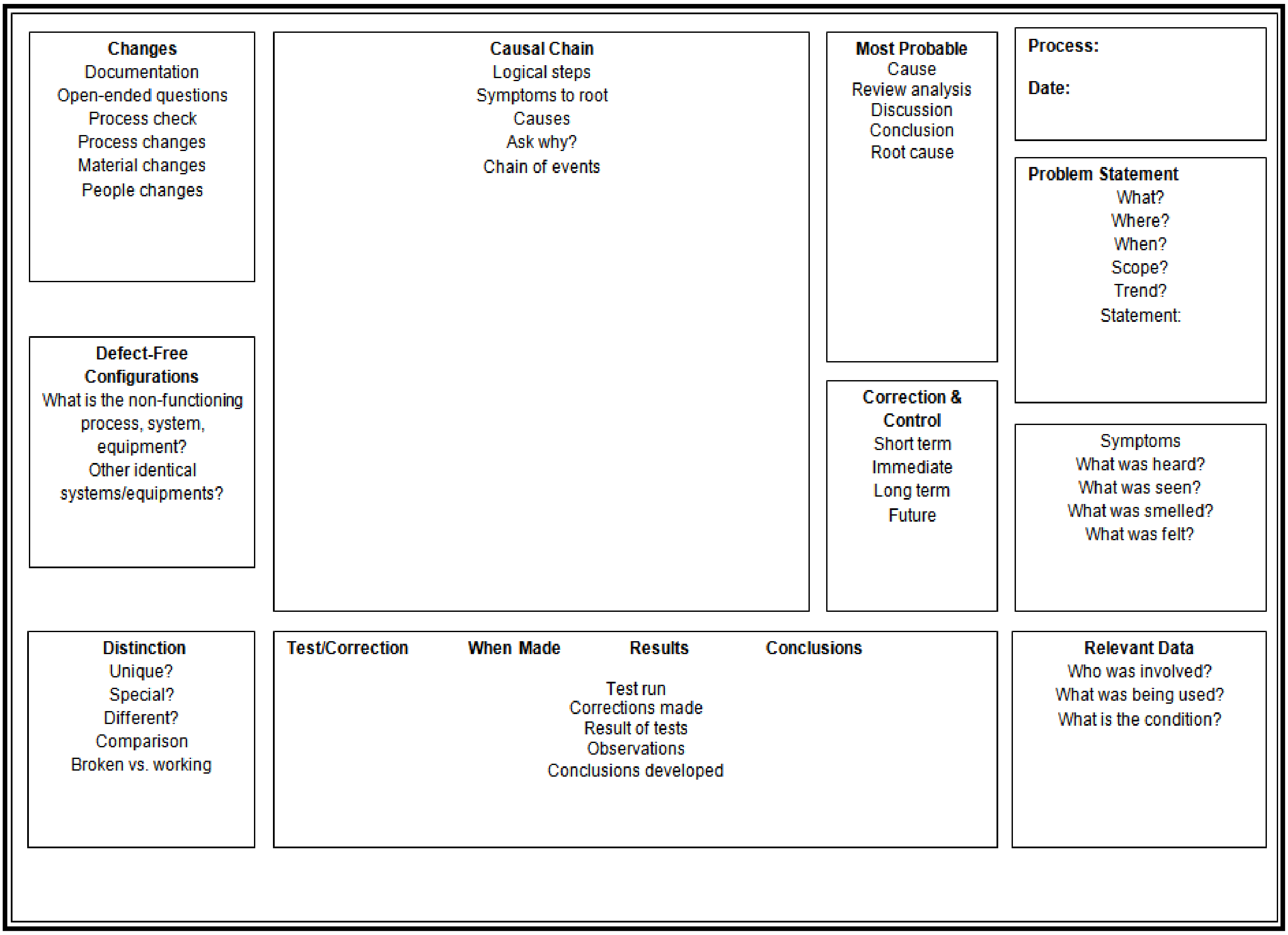
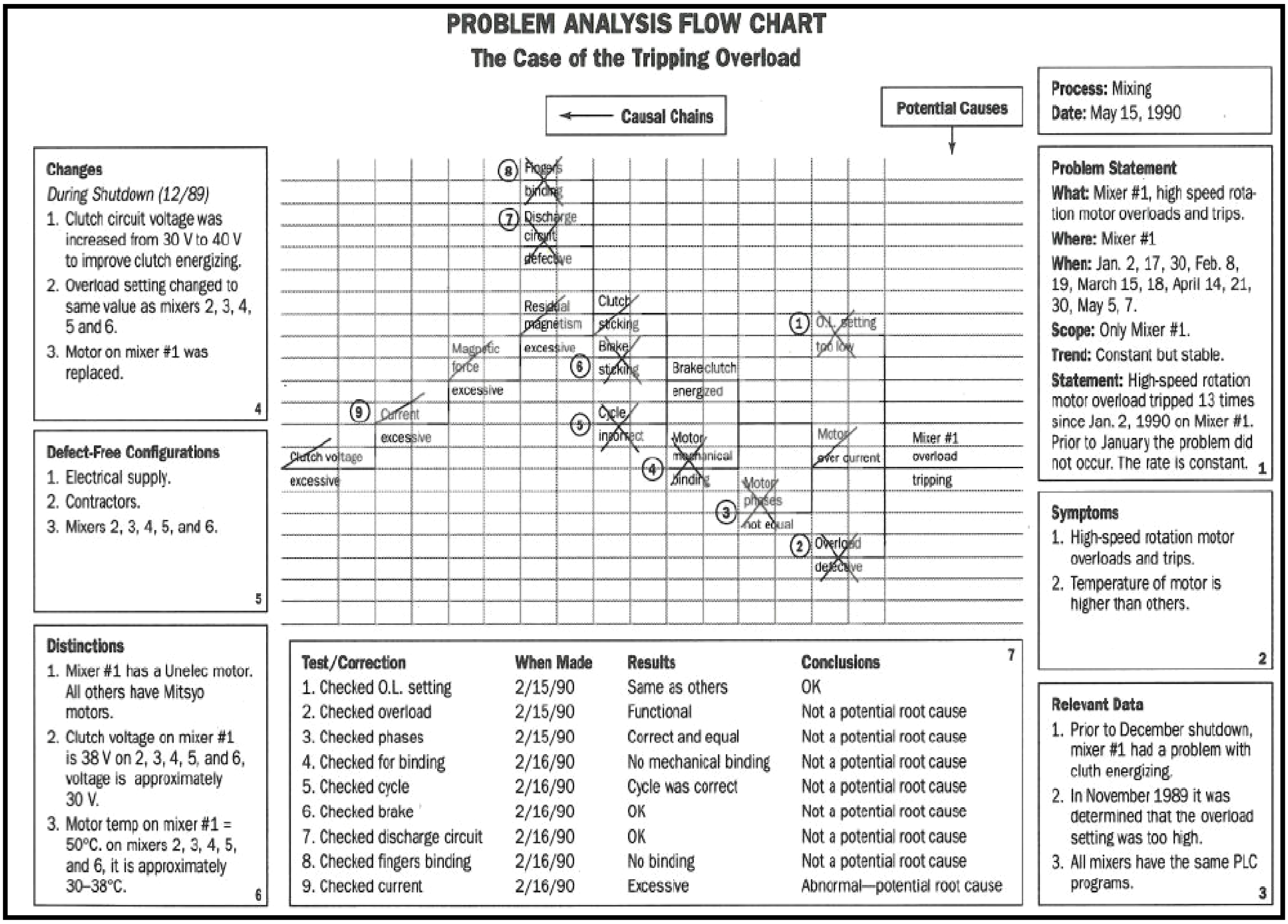
Appendix 1 Problem Analysis Flow Chart (Template) (Sproull 2001)



Appendix 2 Problem Analysis Flow Chart (Example) (Sproull 2001)



Appendix 3 8D Worksheet

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

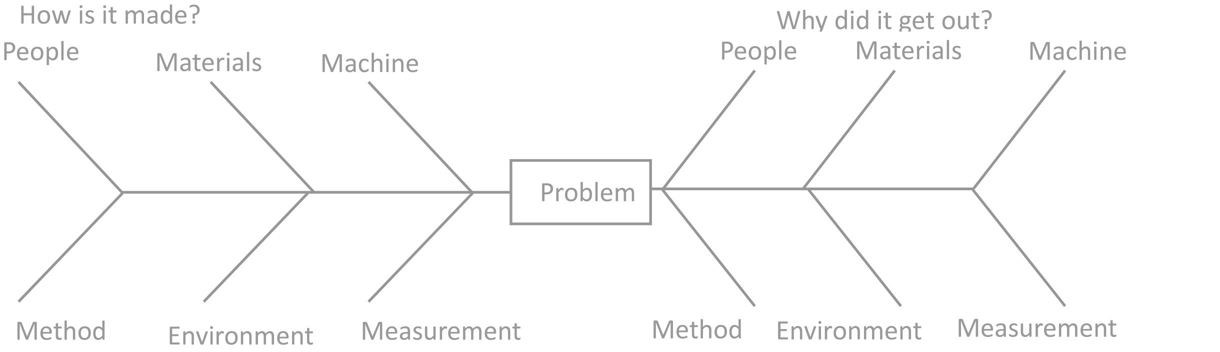
2A	Problem Definition Provides the starting point for solving the problem or Non-conformance issue. Need to have "correct" problem description to identify causes. Need to use terms that are understood by all.	Sketch / Photo of Problem
	Part Number(s):	
	Customer(s):	
	List all of the data and documents 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, lot #s, 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

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

Ask – Why did this happen?

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

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

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 4-1 Failure Documentation Templates for EMC Issue (Input of a new failure)

<table>
<tr><td colspan="6">Input of Failure Documentation</td></tr>
<tr><td colspan="6">Title:</td></tr>
<tr><th colspan="2">Function</th><th colspan="2">Failure Mode</th><th colspan="2">Risk priority Number</th></tr>
<tr><td>Product Type</td><td></td><td>Test Type</td><td></td><td>*Functional Status</td><td></td></tr>
<tr><td>Product Name</td><td></td><td>Customer Spec.</td><td></td><td>*Functional Performance Class</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 rowspan="3"></td><td colspan="2" rowspan="3">*: “Functional Status” and “Functional Performance Class” are for Immunity tests only.</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">Description of failure:</td></tr>
</table>

Appendix 4-2 Failure Documentation Templates for EMC Issue (List of Failures)

List of Failure Documentation							
No.	Customer Spec.	Product Type	Product Name	Software No.	PCB No.	Test Type	Occurrence
001							
002							
003							
004							
005							
006							
007							
008							
009							
010							
011							
012							
013							
014							
015							
…	……	……	……			……	……

Appendix 5 A3 Thinking Template for EMC Issue

Title:	**Team Member:**	**Date:**	**Approval:**	**A3 Report No.:**

1. Background:

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

Product Picture

2. Current Conditions:

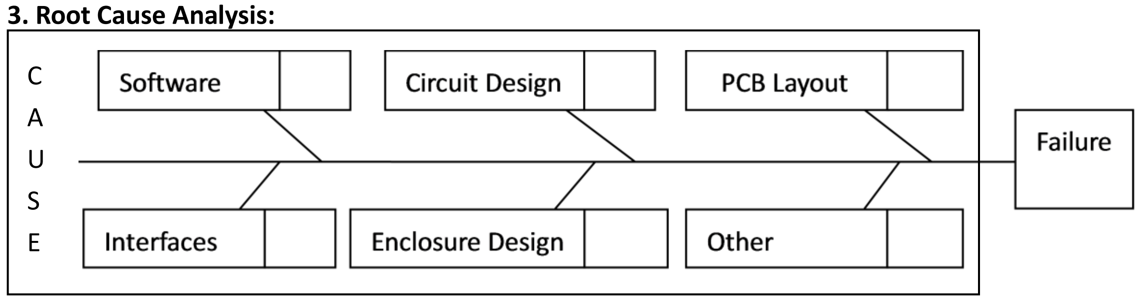
Test Request No.		**For Immunity Only**	**Functional Status**	
Test Type.			**Functional Performance Class**	
Other information		**Occurrence**		

Failure Description:

Failure Description

Failure Picture

3. Root Cause Analysis:



Design Issues	Proposed Causes	Reason to propose

4. Proposed Solution (s):

Proposed Solution (s)	Effectiveness	Type of Solution Temporary/Permanent

5. Implementation Plan:

Tasks	Actions	Responsibility & Date
1		
2		
3		

Result:

Solution Result in text

Solution result in Picture

6. Follow-up Actions:

Potential Risk Assessment: If same failure will happen in other process, or on other product?
Knowledge Capturing: What will you recommend from this failure? Or what design rules need to be standardised?

Appendix 6 Feedback From Experts of Collaborative Company

Engineers		Background	Time spent	Comments
EMC Application Engineers	A	9 years on audio boards design; 8 years on hardware design	4 hours	1. To define a product, ‘Product No., Serial No., Software No.’ would be important. The test failed should be specified with customer’s specification in order to know the exact test type. 2. When refer to the ‘List of Failure Documentation’, ‘Product Type’ and ‘test type’ are necessary. 3. During cause analysis, EMC engineers always perform experimental tests to confirm the root cause, it will be more helpful to know these information.
	B		10 hours	1. It is good to restrict the information of problem solving into this A3 size templates (refer to A3 Thinking template), to make it simple and easy to understand. 2. When go through the integration, it would be very important that engineers could very conveniently fill in the data, otherwise, it will not be able to effectively activate them to use the integration. 3. When doing the root cause, EMC engineer will put all the possible causes and test

				them. 4. At the top level, the classification of root cause in A3 Thinking template is good, as well as the classification of EMC design issues. 5. Engineer B suggests having Test Request No. in the template, which is the unique number for trace the related tests to a particular EMC failure. 6. Sometimes the effectiveness of A3 is limited by the size, when big picture is required, it will be good to have a function that could zoom in the picture, or have a link with other files. 7. The whole flow is quite logical, covers all the problem solving processes, and the knowledge is captured.
	C	19 years on electronic design; 7 years on drive information product design	4 hours	1. The effectiveness of the knowledge would partly depend on the expertise of the engineer who is filling in. It is important to developing elements that could narrow down the content, and keep it objective. 2. Be aware of the security of the knowledge, make sure all the knowledge should be correct. And Engineer A says the knowledge should also be well understandable.
Product Assurance	D	3 years on product assurance;	4 hours	1. Engineer D agrees with the ideal presentation of A3, that people could very easily talk about the problem solving in A3, for example, to post the A3 report in a public place in the company.

		11 years on other position, ex. Product development		2. Engineer D suggests if it would be possible to have other categorisation on the knowledge, root cause, or even the solutions. That will be more detail, and may have very specific use. 3. When refer to the parameter ‘Occurrence’, in fact, sometimes a failure always happens, and easily detected, but it could be easily solved, while another failure barely occur, but is very difficult to detect. The point is the figure would trap people, it would be good to well develop the Risk Priority Number in the integration with consideration on more critical factors.
Continuous Improvement	E		6 hours	1. The knowledge should be documented in a way that could be compatible with different situation; otherwise, it will result in misdirection. 2. Engineer E suggests having a linkage between each piece of knowledge and related A3 report that could help engineer understand what happened behind the knowledge. 3. The visualisation of A3 report is very good and important, so make sure all the input work should be convenient. 4. It is very good to have pictures that show ‘what is before’ and ‘what is after’, it could definitely help readers understand what changes have made during the problem solving.

Appendix 7 Gantt chart of MSc Research Project

	Task Name	Duration	Start	Finish	Predecessors
	MSc Project	**199 days?**	**Fri 01/04/11**	**Wed 04/01/12**	
	Research understanding and Brief	**12 days?**	**Fri 01/04/11**	**Mon 18/04/11**	
	Research understanding	9 days?	Fri 01/04/11	Wed 13/04/11	
	Project aim&objective	3 days?	Thu 14/04/11	Mon 18/04/11	3
	Literature Review	**38 days?**	**Tue 19/04/11**	**Thu 09/06/11**	
	Resource search	6 days?	Tue 19/04/11	Tue 26/04/11	
	Literature filter&reading	16 days?	Wed 27/04/11	Wed 18/05/11	6
	Draft of literature review	9 days?	Thu 19/05/11	Tue 31/05/11	7
	Modification of literature review	7 days?	Wed 01/06/11	Thu 09/06/11	8
	AS-IS situation in the collabrative c	**55 days?**	**Fri 10/06/11**	**Thu 25/08/11**	
	Collect previous documents from th	6 days?	Fri 10/06/11	Fri 17/06/11	
	Document analysis and Face-to-Fac	26 days?	Mon 20/06/11	Mon 25/07/11	11
	Identification of the AS-IS situation	15 days?	Tue 26/07/11	Mon 15/08/11	12
	Research Gap verification	8 days?	Tue 16/08/11	Thu 25/08/11	13
	Framework development	**14 days?**	**Fri 26/08/11**	**Wed 14/09/11**	
	Integration of FMEA and A3	14 days?	Fri 26/08/11	Wed 14/09/11	
	Framework validation	**21 days?**	**Thu 15/09/11**	**Thu 13/10/11**	
	Deliver the framework to the compa	10 days?	Thu 15/09/11	Wed 28/09/11	
	Discussion and feedback	11 days?	Thu 29/09/11	Thu 13/10/11	18
	Thesis preparation	**40 days?**	**Fri 14/10/11**	**Thu 08/12/11**	
	Thesis writing and pre-submission	20 days?	Fri 14/10/11	Thu 10/11/11	
	Thesis modification	20 days?	Fri 11/11/11	Thu 08/12/11	21
	Thesis submission	**19 days?**	**Fri 09/12/11**	**Wed 04/01/12**	
	Viva preparation	9 days?	Fri 09/12/11	Wed 21/12/11	
	Final thesis submission	3 days?	Mon 02/01/12	Wed 04/01/12	24