UNIVERSITY OF LIVERPOOL

JONATHAN SMYTH-RENSHAW

A 4-STAGE FACT FRAMEWORK FOR SOLVING PRODUCT QUALITY PROBLEMS

SCHOOL OF MANAGEMENT
PhD Thesis

Academic Year: 2010 - 2018

Academic Supervisors:
Jorge Hernandez Hormazabal
Andrew Lyons
Iain Reid
April 2018

UNIVERSITY OF LIVERPOOL
SCHOOL OF MANAGEMENT

PhD

Academic Year 2010 - 2018

JONATHAN SMYTH-RENSHAW

4 STEP FACT BASED FRAMEWORK FOR SOLVING PRODUCT QUALITY PROBLEMS

Academic Supervisors:
Jorge Hernandez Hormazabal
Andrew Lyons
Iain Reid

2018

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

Abstract

When Kipling wrote the 'Just So Stories' at the turn of the 20th Century, he could not have realised the impact of his 5W&1H questioning method. In a similar manner, Osborn, the inventor of the brainstorming technique used originally in the field of marketing, has also had a significant impact on this research subject. The history from the early 20th Century to the present date has been considered within this research in the context of production. The research had three aims, is there a direct link between any definitions of quality and the frameworks used to solve a quality problem within production? The weakness of existing quality problem solving frameworks is caused by the tools and techniques used within the framework? The third aim was the development of a conceptual model to compare different quality problems frameworks. Therefore, the research question for this thesis was there an opportunity for the development of a new quality problem solving framework? To address this question, suitable research methods have been reviewed and analysed and a research procedure has been derived. Because of the research, a new framework has been presented and tested. Therefore, the framework was the contributions to knowledge which addresses the weaknesses of existing approaches and a conceptual model for comparing quality problem solving frameworks. In undertaking the research further areas for future work have also been identified. During the research period some of the findings have been published in a recognised journal. To ensure contribution to knowledge, further development of the subject matter and a research method need to de demonstrated, both are present in this thesis.

Unique findings in this research

This summary details the contributions to knowledge and other unique findings within this thesis.

1. No evidence within the literature review of the link between brainstorming as defined by Osborn and the use of brainstorming in quality problem solving. (Chapter 4
2. No evidence within the literature review of a link between the definition of quality and a quality problem solving framework. (Chapter 4)
3. A conceptual model to allow quality problem solving frameworks to be compared. (Chapter 4)
4. The realization that solutions to quality problems fit into a small number of general solutions. (Chapter 4, section 4.7)
5. A new quality problem solving framework (Chapter 4)
6. Two case studies and 4 stories using the framework. (Chapter 5)

List of Acronyms

JUSE – Japanese Union of Scientists & Engineers

P – Probability Value

PDCA – Plan Do Check Act

PDSA – Plan Do Study Act

ppm – parts per million

RCA – Root Cause Analysis

SPC – Statistical Process Control

TPS – Toyota Production System

TRIZ – Teorija Rezhenija Izobreta-telskih Zadach (Russian Problem Solving)

WWBLA – Why Why Because Logical Analysis

WBA – Why Because Analysis

Z – calculated statistic for the 2P test

2P – 2 proportions

5M – Man, Method, Machine, Material, Management

8D – 8 Disciplines

CONTENTS PAGE

Figures

Tables

CHAPTER 1

INTRODUCTION

1.1 Research Background and Motivation

Gilbreth (1921) developed the foundations of the first structured method for documenting process flow, in his presentation ‘Process Charts – first steps in finding the one best way’. The desired outcome of any process is the ‘one best way’. Now, consider the undesirable outcome for any process. Then, consider the next step, the identification of the procedure to use to return the process back to the desired outcome. This research has examined this procedure within the field of product manufacturing. Within this field an undesirable outcome from a process can be described as a problem with the quality of the process. Quality has different definitions, for example, Juran (1974), Crosby (1979), Drucker (1985), Deming (1986), Six Sigma (1988), Taguchi (1992), Chowdhury (2005), Elias (2015) and ISO standard (2017). To address the quality problem, this research will present and assess those quality problem solving frameworks used in the field of the production of products, the frameworks includes Kaizen, Global 8D and Six Sigma.

The motivation for this research has two main elements. The first was that the evidence from the literature review reveals that many of the existing frameworks have been developed during the second half of the 20^{th} century and these frameworks are still are still widely used, this indicates that quality problems are still happening. The question is therefore, do these existing frameworks still provide the correct procedure to ensure the removal of quality problems in the most cost effective and efficient manner? This leads to the second element of motivation which takes up the challenge presented by De Mast in which following a review of quality problem solving frameworks proposed that a ‘studies of how experienced and successful problem solvers work, may enrich the theory about diagnostic problem solving’ (De Mast 2013). This research has presented a framework for problem solving and demonstrated the use of the framework in the context of manufacturing. The final element of motivation was a deep interest in the research topic which is on-going and discussed in this document.

Kent (2017) provides a history of quality management. This is shown in Figure 1 which details the major events from pre-1780 to 2015. The Kent model can be overlapped with the model presented by Weckenmann (2015). This model addressed the period from 1900 onwards, Figure 3, this is presented and discussed in Chapter two. Other subject experts include, Womack et al (1990) who describe the birth of the concept of modern quality as the assembly line of the Model T Car, developed by Ford. Since Ford needed to produce a vehicle to satisfy the large market demand. This goal could only be achieved using standard processes. Therefore, the role of modern quality was established.

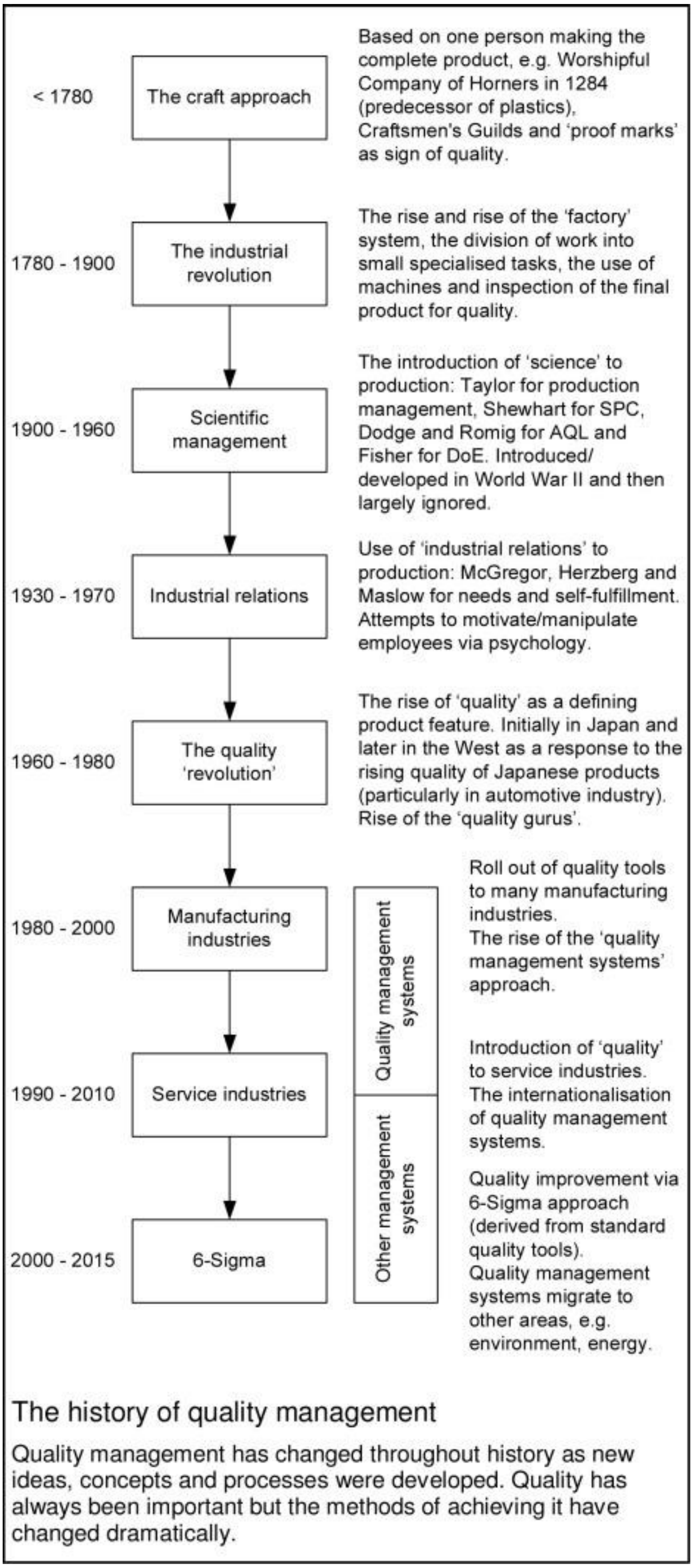


Figure 1 The history of quality management (Kent 2017)

Alongside, the development of the Ford process, other businesses were developing frameworks and techniques/tools to understand quality. Gilbreth(1921) and Shewhart (1931). Shewhart worked for AT&T Bell during the 1920's and 1930's. He developed his ideas and concepts of understanding variation and the concept of Statistical Process Control was given in his book 'Economic Control of Quality of Manufacturing'. Deming was a student of Shewhart and worked alongside him. It was Deming, as part of the USA Marshall plan (1945) to reconstruct Japan after the second world war, who moved the development of quality frameworks and techniques/tools from the USA to Japan. The detail of Deming's work and the subsequent development will be presented in chapter 2.

To provide clarity within this chapter a summary of the Deming approach has been given. The quality problem solving framework, Plan Do Check Act (PDCA) to drive improvement was presented to Japanese business managers JUSE (1950). The use of the framework within Japan and the teaching of quality methods by Deming led to the development of local experts. Ishikawa (1960's) and Taguchi (1960's), are two names associated with quality today. The PDCA framework became the PDSA framework and the use of the Ishikawa 7 quality tools were added to the framework. Other Japanese business representatives visited the USA. Ohno and Toyoda, both from Toyota, visited the Ford factories in Detroit (Womack et al 1990). From their observations, they realised, that both Japan and Toyota could not operate with levels of waste seen in the USA factories, and that a 'copy and paste' model was not an option (Dahlgaard and Dahlgaard-Park, 1999b). The development of the Toyota Production System (TPS) started. Dahlgaard and Dahlgaard-Park, (2006) summarized the TPS as a human-based system with which people were involved with continuous improvements, and the foundation for the system was leadership and empowerment through education and training. Problem solving was undertaken using the concept of Kaizen with the PDSA framework. This was discussed in detail in Chapter 2 and the on-going use of these approaches which are still widely used in 2017. In response to the success of the Japanese business in the global market, the focus in the Western World moved to how to respond to this success. These developments happened from 1980. NBC News showed on prime time, the TV show “If Japan Can… Why Can’t We?” Yet, Dahlgaard-Park (2000), described the Japanese as the world-leader of quality from 1975 onwards. In response, USA companies developed new frameworks. Motorola developed, the now widely used Six Sigma in the 1980’s. The Six Sigma approach was credited to Smith [1998], but Harry [1998] was also involved in the development of Six Sigma. This was discussed in detail in the literature review. Although, widely credited to Motorola, Voehl, (2000) revealed that the Six Sigma methodology was used by the Florida Power and Light company as part of the application for the Deming Prize in 1985, and this was learnt from Japanese counsellors helping with the prize application. During the late 20th century other frameworks, with little academic research have been proposed these include Global 8D used by Ford and A3 used by Toyota. Kepner-Tregoe and Shainin have both proposed framework for problem solving, the latter was copyrighted which means the framework was difficult to research. Many of the frameworks are presented in a circular format, which is at odds with problem solving as the process of solving a problem is linear from problem to solution.

1.2 Research Questions and Aims

The aims of the research were to established from the gaps identified in the literature review, chapter 2, were as follows: -

- One aim of this research was to demonstrate whether there is a direct link between any definitions of quality, as given in the field of this research, and the frameworks used to solve a quality problem within a manufacturing process. Figure 2 provides a visual demonstration of this aim.

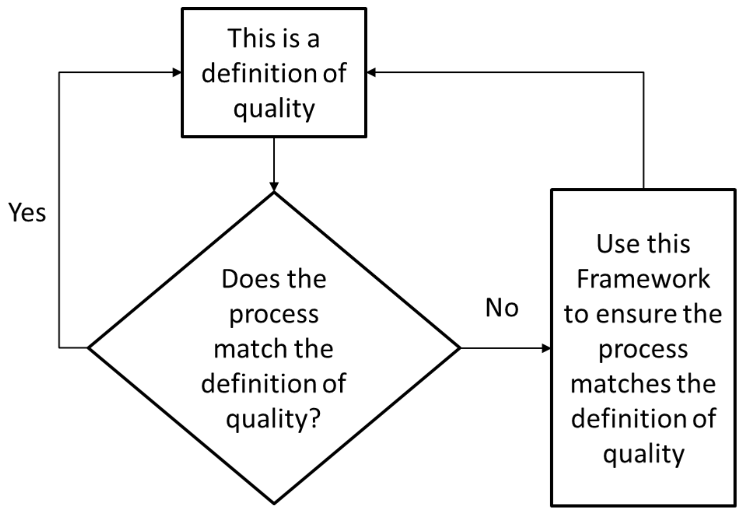


Figure 2: The link between definitions of quality and frameworks to solve quality problems

- The initial aim, led to the next aim which was to show the weakness of existing quality problem solving frameworks is caused by the tools and techniques used within the framework. The different tools and techniques have been detailed in the literature review.
- The final aim was the development of a conceptual model to compare different quality problems frameworks. In doing so the model has been used to demonstrate that the effectiveness of different frameworks cannot be analysed when using the same quality problem if the solution to the problem was known.

In addressing these aims, the research question has been derived. Is there an opportunity for the development of a new quality problem solving framework? This framework must form a direct link to a definition of quality and ensure the tools and techniques within the framework aid the solving of the problem and not hinder it. In doing so this supports the motivation of the research given earlier in this chapter, moving quality problem solving from the 20th century to the 21st century.

1.3 Research Scope and Sample

Within this research it was recognised that the topic of quality problems has many dimensions across all aspects of society both in the past and present. Frameworks to solve quality problems have been developed in the manner briefly described in this chapter and these will be reviewed fully in detail in the next chapter. This research examined the use of quality problem solving frameworks for production of products. It is important to highlight the difference between quality improvement which is proactive and often presented in a circular format and quality problem solving which is reactive, linear from problem to solution. This research has examined quality problem solving.

Having established a number of research aims and a question the outcome was a new framework and the development was presented in Chapter 4. The testing of the new framework has been demonstrated and the benefits are presented in Chapter 5. The step by step detailed process would allow other researchers to follow the process and apply the framework to a future quality problem. The sample in this research was two case studies for which ethical approval has been obtained. Further examples presented as stories have been used to provide a statistically valid sample, this was detailed in Chapter 3 together with other validation approaches. This sample size was small and too small for meaningful statistical tests. To provide further evidence, four further uses of the framework, but these are presented as company neutral, in the context of research can be described as stories. The use of stories has been discussed, in general, the weakness of stories is the validity as a source of data for meaningful research. The combination of this primary data and the stories does provide sufficient data for a meaningful statistical test. However, the sample size was still at the lower bound of the chosen statistical test presented in Chapter 5. Chapter 5, the case studies was not the prime outcome of this research, and the section on further research, provided a discussion of how the framework from Chapter 4 could be used in the future.

1.4 Thesis Structure

This thesis was organised into six further chapters, which are introduced below.

Chapter two provides a review of relevant literature of quality problem solving frameworks. This includes a full review of the definition of quality, a review of research concerning the development, application and evaluation of quality problem-solving frameworks and tools and techniques used within the frameworks. Other relevant secondary data from the appropriate literature has also been considered to provide explanations for the structure of existing frameworks. The outcome of the chapter was the evidence for the main research gaps detailed in this chapter. These gaps have been addressed in Chapter four and demonstrated in Chapter five.

Chapter three details the research method adopted to address and respond to the research aims and questions. Alternative approaches are reviewed, and a justification provided for the chosen approach. The chapter includes a description of the data collection design, execution and analysis. The rationale for the choice of case studies was explained.

Chapter four details the origin and the development of the quality problem solving framework to address the gaps identified in the literature review. The initial framework has been presented, and as part of the development process, examples detailing the use of the framework have been given. The initial framework has been critically reviewed and further development has undertaken to the framework. These developments are shown as a new framework and detailed process to solve production quality problems. To complete the chapter, the development of a conceptual model to compare different quality problem solving frameworks was presented. This conceptual model was used in the next chapter to provide a justification for, why it was not possible to use multiply frameworks to solve the same quality problem.

Chapter five presents the case studies which were undertaken to demonstrate the quality problem solving framework given in the previous chapter. The benefits of the framework are given, and the case studies have both had ethical approval.

Chapter six presents the discussion of the research. Chapter seven was the last chapter of this thesis which provides an overview of the findings and the contribution to knowledge from the research. This chapter also includes the limitations and further research opportunities for research presented in this thesis. The research gaps established in the literature review are discussed and how this research has addressed the gaps was discussed.

CHAPTER 2

A REVIEW OF LITERATURE

2.1 Introduction

A literature review is a critical and analytical summary of the findings taken from appropriate primary, secondary and can include tertiary literature sources (Mays et al 2001). This literature review has used secondary sources. The approach within this literature review was to provide a detailed review of the research topic detailed in Chapter 1. The objective of the review was to demonstrate the evidence for the research questions detailed in Chapter 1. The review was structured in a hierarchy of existing information and data, to provide further insight appropriate analysis has been undertaken. This approach was consistent with views given in the literature. Mays et al (2001) describe the review as required to ensure exposure of any gap in existing knowledge, to build the foundations of the research understanding and to identify principal areas of research uncertainty. Whittemore and Knafl (2005) state that by utilising methods of qualitative research and combining the data analysis from the reviews, bias and error can potentially be reduced. The hierarchy within this review began with important definitions of quality within a business context. Following the initial analysis of the definitions, a more detailed assessment was undertaken to provide suitable definitions appropriate to quality problem solving frameworks. This has addressed the question raised in Figure 2 in the previous chapter. The next section of the chapter provides a detailed review of frameworks which have been used to solve quality problems. The review was split into difference sections, broadly, the split was determined by the level of academic literature review available. Several frameworks have little or no academic review. One framework, as mentioned in Chapter 1, has been copyrighted, Shainin, and therefore, the presentation of this framework was limited to literature available in the public domain. Within the review of the frameworks, the tools and techniques used as part of the frameworks have been identified. This leads to the next section of the chapter, the literature review of tools and techniques. Within this review, the detail of the tool and technique was described and discussed. This was descriptive in nature, but necessary to highlight the research gaps. Where appropriate literature in which the tools and techniques have been evaluated this has been included. The final section of the chapter provides an assessment of which frameworks which have been used in recent times. The outcome of the chapter was a comprehensive review of the research topic, and the research gaps have been clearly presented.

2.2 The Definition of Quality within business

This section of the chapter details the review of literature undertaken with respect to definitions of quality within business. What is Quality? This question is very broad. To provide a context and boundary within this research, the research has focused on the meanings of quality found within manufacturing. A non-exhaustive chronological list of various definitions was given in Table 1.

Year	Source	Definition
1974	Robert Pirsig	"The result of care."
1974	Joseph M. Juran	"Fitness for use."
1979	Philip B. Crosby	"Conformance to requirements." (FULL)
1985	Peter Drucker	"Quality in a product or service is not what the supplier puts in. It is what the customer gets out and is willing to pay for."
1986 1988	W. Edwards Deming	Concentrating on "the efficient production of the quality that the market expects," and he linked quality and management: "Costs go down and productivity goes up as improvement of quality is accomplished by better management of design, engineering, testing and by improvement of processes."
1988	Noriaki Kano	A two-dimensional model of quality: "must-be quality" and "attractive quality."
1988	Six Sigma – definition	"Number of defects per million opportunities."
1991	Gerald M. Weinberg	"Value to some person".
1991 1992	Genichi Taguchi	"Uniformity around a target value." and "The loss a product imposes on society after it is shipped."
2005	Subir Chowdhury	"Quality combines people power and process power."
2015	Victor A. Elias	"Quality is the ability of performance, in each Theme of Performance, to enact a strategy.
2017	ISO 9000	"Degree to which a set of inherent characteristics fulfils requirements (defined as need or expectation)."
2017	American Society for Quality	"A combination of quantitative and qualitative perspectives for which each person has his or her own definition; examples of which include, "Meeting the requirements and expectations in service or product that were committed to" and "Pursuit of optimal solutions contributing to confirmed successes, fulfilling accountabilities". In technical usage, quality can have two meanings: a. The characteristics of a product or service that bear on its ability to satisfy stated or implied needs; b. A product or service free of deficiencies."

Table 1: Definitions of quality found within manufacturing

Figure 3 provides an overview of the development of quality management across the 20th and 21st Century. This provides further detail to the Figure 1 presented in Chapter 1.

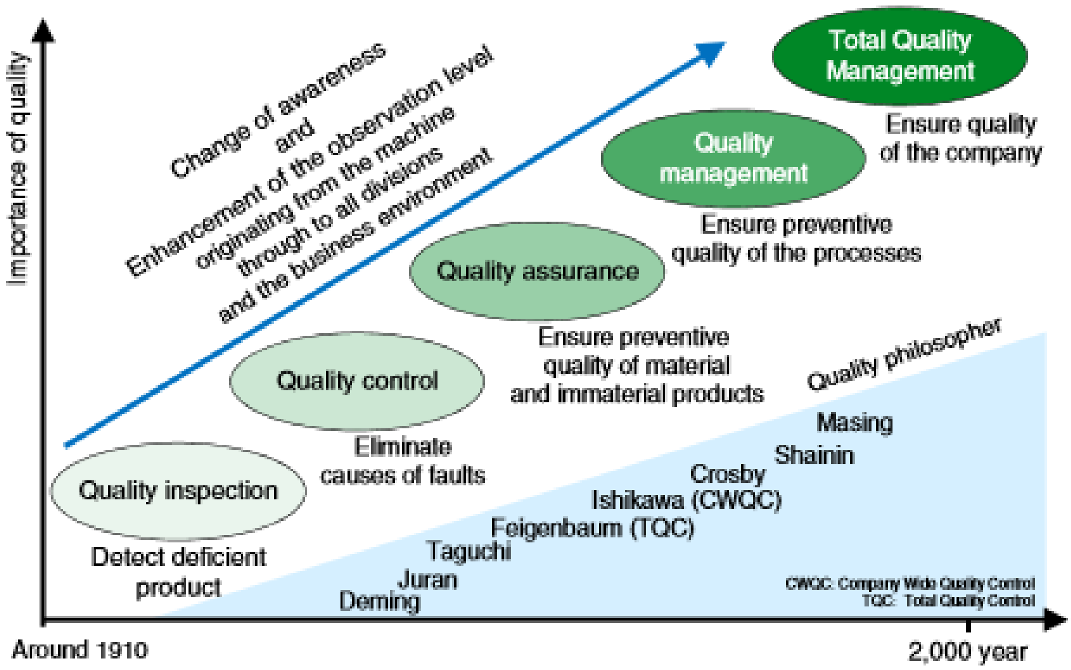


Figure 3: Overview of concepts in quality management (Weckenmann 2015)

Much of the development of modern quality management thinking can be traced to the work of Ford and Shewhart in the period of 'Quality inspection' (Weckenmann 2015). In more recent times, quality cannot be considered the preserve of the automotive sector, and quality has a broader meaning to all businesses, as given by the various definitions given earlier in the chapter. An important milestone in current quality thinking was the learning from the development of the Toyota Production System, as presented by Womack & Jones (1990). The development of the Toyota Motor Car and the Total Quality System (TQS) system can be correlated to Japanese visits to Ford, and Deming worked with Shewhart [1980]. Ghobadian et al (1994) proposed that the 'discovery of quality' and its application can be traced to the visits of Deming and Juran to Japan in the 1950's, as part of the restructuring following the Second World War. However, the development of the Ford Model T assembly line required a control of quality via (mass) inspection as given on Figure 3. Garvin (1984) details how this 'quality' message, discovered in Japan, spread back to the US, the Pacific Rim and onto Europe during the 1980's. The 'experts' views of quality from the last quarter of the 20th century are presented as follows, the rationale for this timeframe was to provide a link to the frameworks later in the chapter. Deming (1946), part of the USA Marshall plan team to help rebuild Japanese industry after the second world war was widely seen as the person who started the Japanese quality revolution. Deming was also associated with Statistical Process Control (SPC), again a technique he learnt from Shewhart (1931), and other quality problem solving techniques. The Deming Cycle - Plan, Do, Study, Act (PDSA) was known as his approach to quality improvement. This approach has been detailed later in the Chapter. Deming (1980) stated that the customer's definition of quality is the only one that matters. Juran was another ‘expert’ to visit Japan and he defined quality as ‘fit for purpose or use’ (Juran et al, 1974). Crosby (1980) claimed ‘quality was free’ and improvement was brought about on a continuous basis towards important goals, not project by project. Crosby proposed that quality management can be measured using a maturity grid with five phases from uncertainty to certainty via awakening, enlightenment and wisdom. To aid movement through the phases, Crosby also details a 14-step process for quality development. Feigenbaum (1986) defines quality as the ‘total composite product and service characteristics of marketing, engineering, manufacture and maintenance through which the product and service in use will meet the expectations of the customer’. Chase & Aquilano (1989) state that Feigenbaum’s contribution was to determine that all quality approaches are synergistic, that is, quality improvements need to be applied to all aspects of the business. Groocock (1986) defines quality as ‘the quality of a product as the degree of conformance of all the relevant features and characteristics of the product to all the aspects of a customer’s need, limited by the price and delivery he or she will accept’. This was accepted as a synthesis of Crosby and Juran’s perspective on quality, and therefore recognises the trade-off between product quality and its price. Groocock builds on earlier work of other experts, Deming and Feigenbaum, and proposed a ‘chain of quality’ and customer requirements that need to be built into each step of the chain, like Crosby’s, conformance to requirements.

Groocock also proposed a quality improvement model which was built in 14 steps, in a similar vein to Crosby, with built in review before using the same process for the next improvement project. In 1960, Taguchi defined quality as ‘on target with minimum variation’ (Wheeler, 1995). In 1986 he revisited his definition and proposed quality was the ‘loss imparted to the society from the time a product was shipped’, therefore, the smaller the loss the more desirable the product. Implicit in Taguchi’s philosophy was the premise that ‘in a competitive economy, continuous quality improvement and cost reduction are necessary for remaining in business’ (Taguchi, 1986). Taguchi believed that 100% conformance was impractical which contradicts Crosby and Groocock, believing instead it was possible to reduce variation for key product characteristics around the desired target. Ishikawa defines quality as the ‘development, design, production and service of a product that was most economical, most useful, and always satisfactory to the consumer’ (Ishikawa, 1985). Ishikawa believed that quality control was not just about the product but encompasses the whole supply chain. His views were like those of Feigenbaum and Groocock.

Expert	Timeframe	Definition of Quality
Deming	From 1950’s	Customer's definition of quality is the only one that matters
Juran	From 1950’s	Fit for purpose or use
Crosby	From 1960’s	Quality is free
Taguchi	From 1960’s	On target with minimum variation
Ishikawa	From 1960’s	The development, design, production and service of a product that is most economical, most useful, and always satisfactory to the consumer
Feigenbaum	From 1980’s	Total composite product and service characteristics of marketing, engineering, manufacture and maintenance through which the product and service in use will meet the expectations of the customer.
Groocock	From 1980’s	The quality of a product was the degree of conformance of all the relevant features and characteristics of the product to all the aspects of a customer’s need, limited by the price and delivery he or she will accept.

Table 2: The expert definition of quality

Table 2 provides a summary of the definitions with the timeframe. Except for Crosby, the definitions all have a common theme of the customer expectations being fulfilled. Ishikawa, Feigenbaum and Groocock provide greater clarify and scope to the meaning of quality. To provide a visualisation of quality, two schools of thought have been developed, the concept of conformance to specification (tolerance), that was, outcomes within the tolerance can be considered 'quality' and those outside the tolerance can be considered 'non- quality'. The other school of thought, was that proposed by Taguchi. He stated the only state of quality was when the outcome hits the target. All other outcomes would result in some level of 'non-quality'. The further the outcome from the target the greater the level of 'non-quality'. Figure 4 provides the visualization of the two schools of thought.

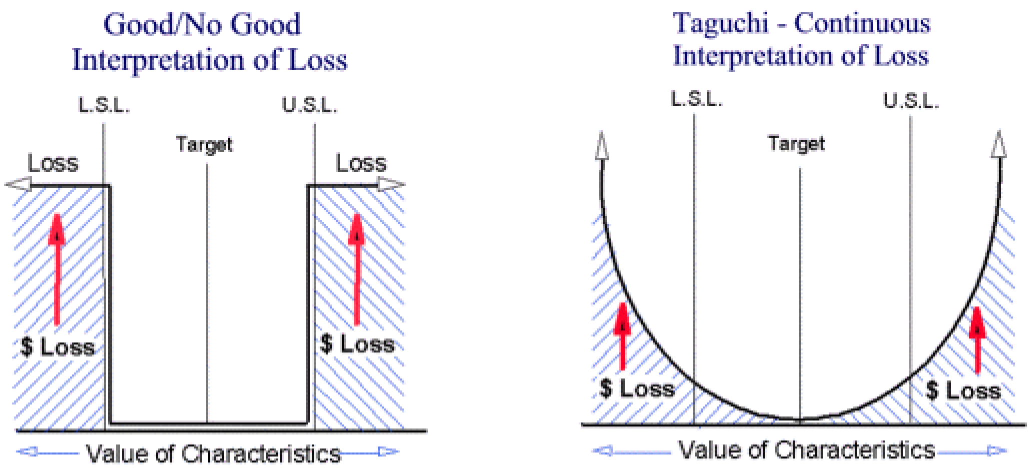


Figure 4 Conformance to Specification v Hitting the Target

(www.leansixsigmadefinition.com (2017))

2.2.1 Summary of findings

This section has discussed the definitions of quality within the context of manufacturing. This was linked to the first research aim and Figure 2 given in Chapter 1. The definitions are all from the 20th century and each 'expert' has their own definition. However, these definitions can be split into two general sets of thought process. The first definition was 'conformance to specification', supported by Deming, Juran, and others, and the second was 'on target with minimum variation', the definition of Taguchi only. Within Chapter 4, the Taguchi definition has been used, thus forming a link from the research aim concerning 'what is quality?' and the problem-solving framework. The next section concerns the frameworks which are used to solve quality problems.

2.3 Quality problem solving frameworks

2.3.1 Introduction

This section of the chapter provides a review of the quality problem solving frameworks. In each case, the detailed structure of the framework was given. Figure 5 was given as a quality control circle for manufacturing of products. The box identified as 'Failure' presents the different frameworks to address 'failure' within the business process.

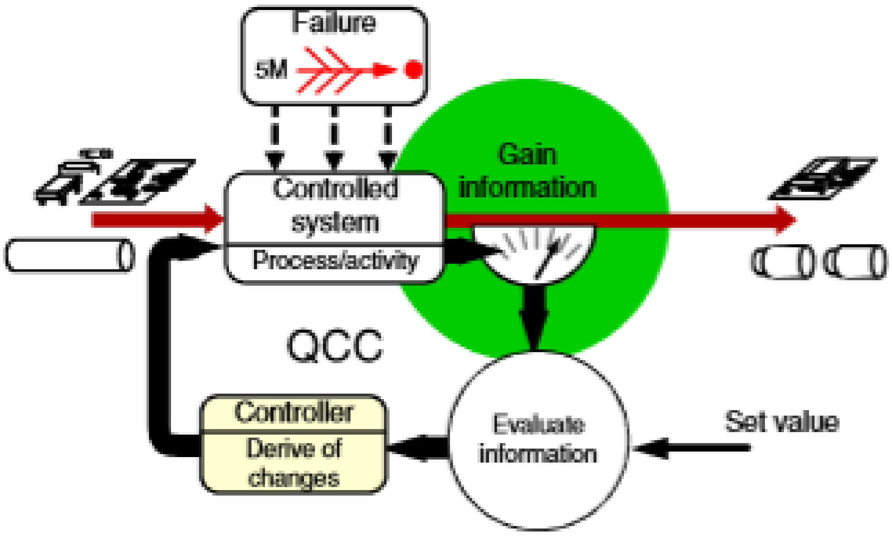


Figure 5 Quality control circle for manufacturing (Weckenmann et al 2015)

Weckenmann et al (2015) describe how a 'variety of methods such as the seven tools of quality management (Q7), the PDCA-cycle by Deming or the "Five-times-Why" strategy' were developed to support 'the identification and correction of errors'. Weckenmann et al (2015) also describe how other tools and techniques have been used, 'the consideration of a whole production process with many entities enabled the utilization of statistical methods on practical problems'. This resulted in the definition and wide-spread use of Statistical Process Control (SPC) to react on changes in time to avoid the production of waste. Design of Experiments (DoE) was used, facilitating the efficient identification and adjustment of significant input parameters to gain optimal output results regarding product quality.' The selection of the frameworks follows the model given by Weckenmann et al above, that was, the framework must address failure, in this research this was a quality problem in production of a product. The frameworks have been presented in two sections, those with academic research and those of interest but with little or no academic research. This was detailed in the introduction of this chapter.

2.3.2 Frameworks with academic research

This section includes those frameworks with academic research.

2.3.2.1 PDSA cycle

Figure 6 lays out the time line for the history of the PDSA cycle. The black box defines the area of interest within this research.

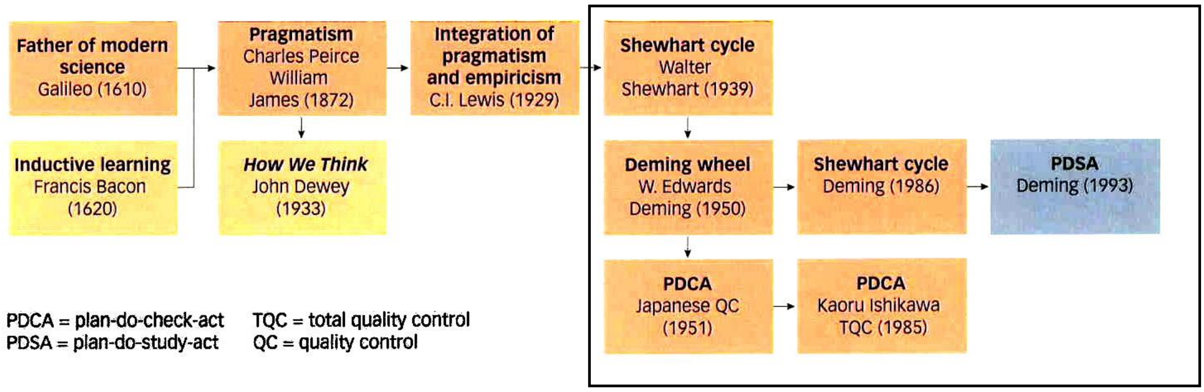


Figure 6: The evolution of the scientific method and PDSA cycle (Moen & Norman 2010)

The original Shewhart cycle which was developed and presented in 1939 is given Figure 7.

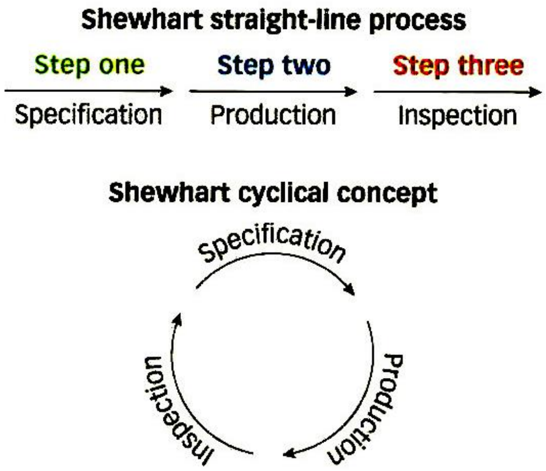


Figure 7: The Shewhart cycle (Moen & Norman 2010)

This cycle was developed by Deming and in 1950 he presented the cycle shown in Figure 8.

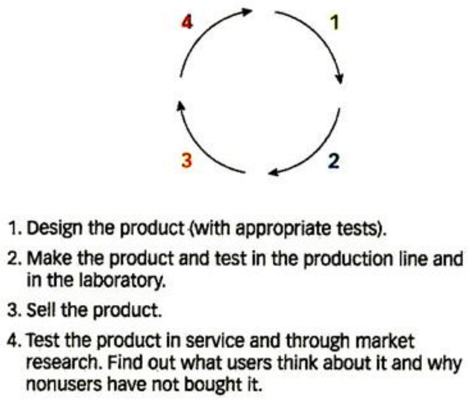


Figure 8: The Deming cycle (1950) (Moen & Norman 2010)

Moen (2009) who worked with Deming presented the history of the PDSA cycle. The timeline of events was as follows: -

- The Japanese developed the PDCA cycle based on Deming's seminars to Japanese executives in 1950 (no one person claims authorship). However, Imai (1986) claimed it was Japanese executives who recast the wheel. Therefore, at this point the original cycle was split into different cycle models.

- PDCA cycle was used for implementation and compliance, and has not changed in the last 40 years
- Deming evolved the PDSA from 1986 until 1993 and always called it the "Shewhart Cycle for learning and improvement".

There are important differences between the PDCA cycle as used by the Japanese and the rest of the world. The Japanese PDCA cycle is shown in Figure 9.

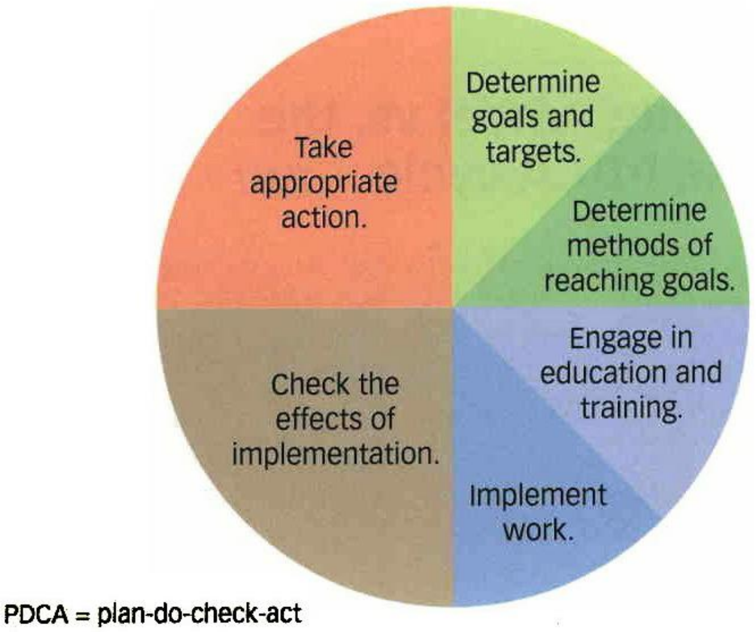


Figure 9 The Japanese PDCA cycle (Moen & Norman 2010)

The PDCA cycle, with the two elements within the Plan (P) phase, goals and targets and methods described by Ishikawa was traced back to Dr. Mizuno in 1959. Lilrank & Kano (1989) state the 7 basic tools (check sheet, histograms, Pareto chart, fishbone diagram, graphs, scatter diagrams, and stratification) highlight the central principle of Japanese quality. These tools together with the PDCA cycle and the Quality Control (QC) story format became the foundation for problem solving (kaizen) in Japan. Kaizen is discussed later in this chapter. Elsewhere in the world, the PDSA cycle has evolved and Moen et al. (1991) and Langley et al. (1994) presented the cycle given in Figure 10.

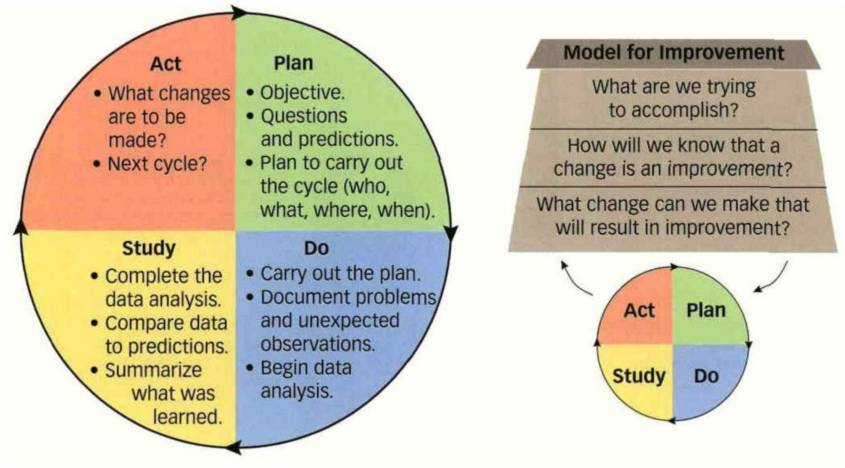


Figure 10 The PDSA cycle 1991 and 1994 (Moen & Norman 2010)

Flood (1993) considered the weaknesses of the PDSA cycle included the lack of a well-defined methodology and that the work was not adequately grounded in human relations theory. The difference seen between the Japanese approach with the 7 quality tools and the approach given in Figure 7, which adds to the original Deming concept could explain the lack of methodology. Donnelly and Kirk (2015) describe how the PDSA model has been used as an effective change management model for the NHS and concluded that the PDSA cycle 'can appear somewhat cumbersome and complex' but that the model provides a 'structure for a natural process whereby groups/teams initiate change within their system, whether within healthcare or elsewhere.'

Other recent examples of the use of the PDSA cycles include improving GP Diabetes Management: A PDSA Audit Cycle in Western Australia (Porter et al 2009), the preparedness for, and management of the norovirus in NHS Scotland (Curran and Bunyan 2012), the continuous improvement of online course design (Gazza 2015) , and the quality improvement project to decrease emergency department and medical intensive care unit transfer times (Cohen et al 2015**).** The date of the references provides an indication that the framework was used today.

2.3.2.2 Kaizen

Kaizen has been regarded as one of the crucial factors in the pursuit of industrial competitiveness indices such as productivity, manufacturing quality, lead time, and flexibility in the automobile industry as well as others (Imai 1986; Winter 2003; Anand et al. 2009; Fujimoto 2014). As mentioned in the previous section, the concept of Kaizen was developed from the Deming PDSA cycle. This was supported by Imai who states that to implement Kaizen, companies will adopt the Plan-Do-Check-Action (PDCA) cycle to solve both unit-functional and cross-functional problems in their activities (Imai, 1986). Using Figure 9 from the previous section it was possible to position the development of Kaizen within the PDCA cycle. This was shown in Figure 11 within the box.

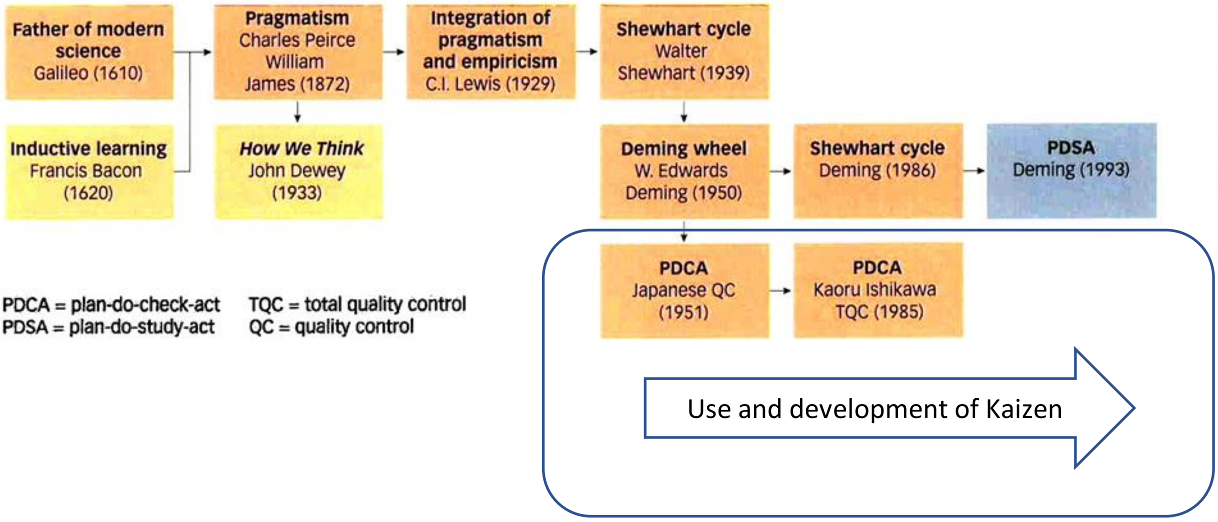


Figure 11: Kaizen and the PDSA cycle (after Smyth-Renshaw 2017)

The history of the codification of Kaizen was presented by Ohno's (1978) Japanese edition of the "Toyota Production System". Other major publications that introduced the Japanese philosophy of kaizen to the West include "Kaizen" Imai's (1986) in which it detailed how continuous improvement or Kaizen was a strategy normally adopted by a company where teams of employees at various levels through cross-functional effort with collective talents within the company work together proactively on improving specific area within the company

(Imai, 1986). ; Womack et al.'s (1990) "The Machine that Changed the World"; and Liker's (2004) "The Toyota Way". This genre of literature set the stage for many of the West's attempts at catching up with the late 20th century Japanese quality movement. 'Brunet and New (2003) conclude that in attempting to decode the competitive success of industrial Japan, researchers and practitioners in the West, and those in the Anglosphere, have identified with the tangible tools and techniques of the Japanese quality management philosophy of kaizen.' However, Japanese Kaizen has a deeper meaning than "continuous improvement" (Anand et al., 2009) and a significantly wider scope than that applied to business operations. Therefore, the broad philosophy cannot be easily transplanted to another culture despite the breadth of applications observed in the West; these are only the tangible tools and techniques. Macpherson et al (2015) conclude the 'tangible tools are evident in manufacturing plants across North America, Europe, the United Kingdom, Australia and New Zealand. In businesses as diverse as Caterpillar (Illinois, USA), Harley Davidson (Wisconsin, USA), Husqvarna (Jönköping, Sweden) and GDM Group and Q-West (Wanganui, New Zealand), the tools of kaizen are used to enhance production techniques, systematise operations and seek greater contributions from employees.' Further analysis by Macpherson et al (2015) conclude that outside Japan kaizen was viewed as 'somewhat' simplistic and 'largely misinterpreted and misunderstood'. In the best applications, the tools and techniques have been used with 'real diligence' and achieved short term improvements. The summary of past studies describes Kaizen as consisting of numerous small incremental innovations that (1) have small variability in scale/size, (2) change the way products are made and are categorized as process innovations, (3) are mutually independent and have no interaction with other Kaizen activities, and (4) are implemented mainly by workers, work-teams, and work-team/group leaders. In the 1980s, scholars tended to explain the cause of differences in firms' manufacturing performance as the Japanese way of manufacturing management, particularly in the automobile industry (Hayes and Clark 1985).

In particular, Toyota Production System (TPS), also called Lean Production System (LPS), attracted scholars' and practitioners' interest for study and benchmarking (Monden 1983; Womack et al. 1990). Although Womack et al. (1990) identified the importance of TPS/LPS, the fact that it has been changed through evolutionary processes has been overlooked (Fujimoto 1999). Womack et al. (1990) conveyed the importance of the softer aspects of ''how to use the machine'' of process innovation, such as LPS, but downplayed the importance of changes in LPS through Kaizen. Macpherson et al view was further supported by Kiran (2017) who studied Kaizen and presents Kaizen as an umbrella of tools and techniques for 'changes for the good', which is the Japanese meaning of Kaizen. Kiran's model is shown in Figure 12.

Figure 12: The Kaizen Umbrella (Kiran 2017)

The research into Kaizen could conclude that the approach was a name given to an umbrella for tools and techniques which follow the PDSA cycle. If this view of Kaizen was adopted, then the research of the PDSA cycle has been presented and the tools and techniques will be presented later in the chapter. Therefore, the strengths and weaknesses of Kaizen would be covered by the analysis and assessment of PDSA and any of the tools and techniques used under the Kaizen umbrella. One technique was of interest within this research, the 4 Wives and 1 husband, and has been reviewed later in the chapter. Other techniques such as brainstorming and creative questioning are also reviewed. The other techniques/tools are not within the scope of this research.

2.3.2.3 A3 method

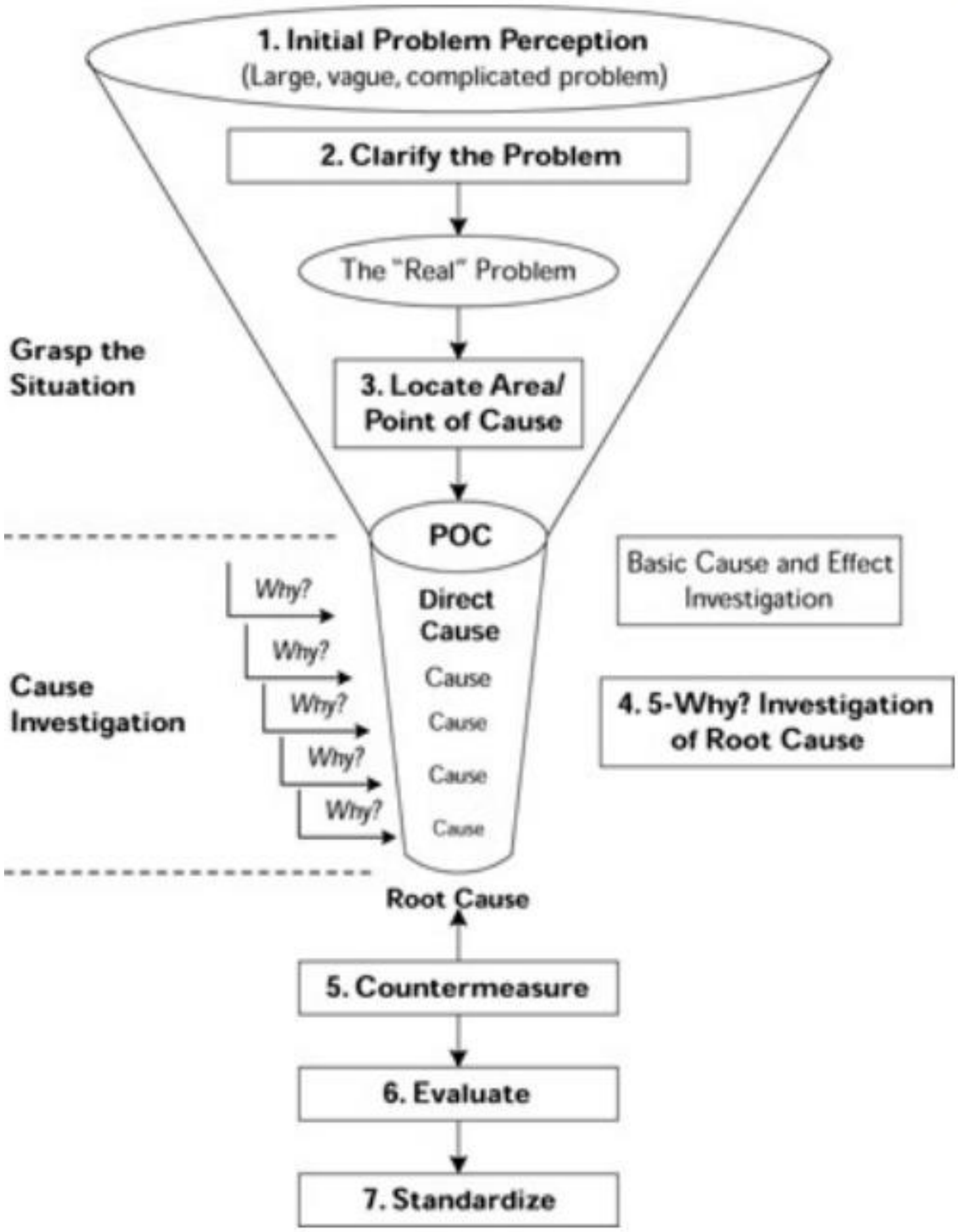


Figure 13 The A3 framework (Matthews 2011)

The A3 framework is given in Figure 13. The framework was developed in Toyota, the problem-solving method called A3 based on the Deming Plan-Do-Check-Act cycle (Liker &

Meier, 2006). Conventions across all types of A3 reports include: reports are on a single sheet of A3 size paper (11 x 17 inch); follow a general structure; and rely on figures and graphics to tell the 'story'. The A3 method was originally applied in a manufacturing environment for problem solving and process improvement, but it has been implemented in other environments such as healthcare (Ghosh, 2012) and in higher education. The approach has been used in teaching process improvement in health care executive MBAs (Visich, Wicks, & Zalila, 2010). Sobek & Smalley (2008) in their detailing of the Toyota A3 method, describe a 7-stage process. Stage 2 describes the problem statement, the key points to consider in this stage are as follows: -

- Depict an overview of the current state of the process or system visual
- Highlight the key factors in the current state
- Identify the real problem in the current state. What is it? What is it not?
- Use quantitative measures to depict the status of the current state (not just qualitative opinions).
- Summarize relevant information pertaining to the current state

Matthews (2011) describes stage two which is the current condition, as being split into four sub-stages. These are: -

- Background- Company
- Problem Statement
    - -Standard (expectation or norm)
    - -Current Situation (what is happening now)
    - -Discrepancy (gap or problem)
- Extent
- Rationale Risk Assessment

The background was both a resume of the problem solver's position in the organization and a description of the events seen as the problem occurs. Toyota has a culture deeply engrained in the determination of standards. The adherence to standards was the norm. Furthermore, if there was no standard there was an expectation or norm. Matthews (2011) states 'without this baseline, it would be impossible to understand the magnitude of the perceived problem, much less begin the process of solving the problem'. The current situation was defined as the way things are now. The discrepancy was the difference between the standard and the current situation, but this must be measurable or a recognizable difference. The Extent was determined by asking the following questions: -

When? How often? Where? How long? What is it doing? What is affected? What types of occurrences?

Once this problem statement was complete it was important to determine the Point of Cause (POC). The rationale was used to determine which problem needed immediate attention and how the problem fits into the organization. All problems should be evaluated as to: - Importance? Urgency? Tendency? The process begins with defining the current situation. The next step was to identify the root cause of the problem. A3 Thinking stresses the need to uncover the root cause using the 5 Whys tool which repeatedly asks, "Why is this problem occurring?" until the root cause was determined. Once the cause was understood, countermeasures are developed and implemented. After implementation, checking makes sure that the expected improvement has been realized. Finally, the improvement was standardized into the process. Sobek and Smalley (2008) present A3 thinking as a general-purpose tool for problem solving and provide templates and "how-to" descriptions. Other descriptions of A3 include Liker (2004), Liker and Meier (2006), Shook (2008, 2009). Lee and Kuo (2009) describe the A3 method as using a Root Cause Analysis method structured to ascertain the root causes for the problems. The "5 why's" method was a common technique for RCA. The final

"Why?" in the analysis of each storm cloud/problem generates an implementation plan checklist. To visually view the process of the “5-why’s”, a Cause-and-Effect Diagram or a Fishbone Diagram was often helpful. Sobek & Smalley (2008) describe the A3 report being used in different situations including problem solving, project status, and proposals. The A3 Report was intended to be flexible and adaptable to the problem at hand. ‘In all cases, the tools are effective only to the extent they engender a style of thinking that was rigorous and thorough, a style of communication that focuses on hard data and vital information, and a style of problem-solving that is collaborative and objective.’ (Sobek & Smalley, 2008, p. XV). There are several case studies; these are mainly in the health sector. An example was given from India. Ghosh (2012) details the use of A3 process within Health Care. The case study looks at a Radiology department within an Indian Hospital. The key benefit was that the department could deliver patients’ electronic X-ray reports and thus improve patient care. The cost savings by Western standards are small in the region of five thousand pounds, the saving being on paper expense and productive time of the transporters. Ghosh (2012) then provides an interesting discussion having applied the method, stating that the method does not require any sophisticated mathematical or technical training, but an A3 size paper, a pencil and basic literacy to write. This was because people using the A3 process requires group discussion and following the A3 process based observing the problem first hand. It was the deeper contextualized understanding which helped the members in this case study to jointly transform knowledge and improve this hospital process.

2.3.2.4 Global 8D

The background to Global 8D was the US Military Standard MIL-STD-1520C which had the following scope:

'This standard sets forth the requirements for a cost-effective action and disposition system for non-conforming material. It defines requirements relative to the interface between the contractor and the contract administration office on non-conforming material.'

A review of the standard does not reveal any guidance on how to define problems, only the need to do such activities and record them for future reference.

In the 1960's The Ford Motor Company developed a problem-solving tool kit. This was known as Team Oriented Problem Solving (TOPS) (Doane, 1987). After a period of use the tool kit was rebranded during the 1980's and became known as the 8D-method and in a further iteration, Global 8D (G8D). The approach has historical roots in the quality standard MIL-STD 1520C "Corrective Action and Disposition System for Nonconforming Material", issued by the US military. The Global 8D approach uses eight disciplines known as 8D. Smith (2005) who worked within Ford, provides insight into the history, framework and direction of the Ford G8D framework. Established in the 1980s to provide a disciplined and systematic process for solving problems and preventing their recurrence, the result of combining the best practices of several methodologies, the eight steps are to:

1. Prepare the process.
2. Establish a team.
3. Describe the problem.
4. Develop an interim containment action.
5. Define and verify root cause.
6. Choose and verify permanent corrective actions.
7. Prevent recurrence.

8. Recognize team and individual contributions.

Smith (2005) proposes that when used properly, G8D has tremendous value. It encourages teams to really define the root cause by carefully defining what the problem is and is not working and asking, "Why, why, why?" G8D provides a high-level organisation of the problem-solving activity and is a useful communication and corporate memory tool. G8D was still used extensively with Ford suppliers (2000's). As to the future, Smith (2005) observes that many Ford teams are choosing to use the Six Sigma (DMAIC) methodology in place of G8D. This trend was expected to continue. Figure 14 shows the structure.

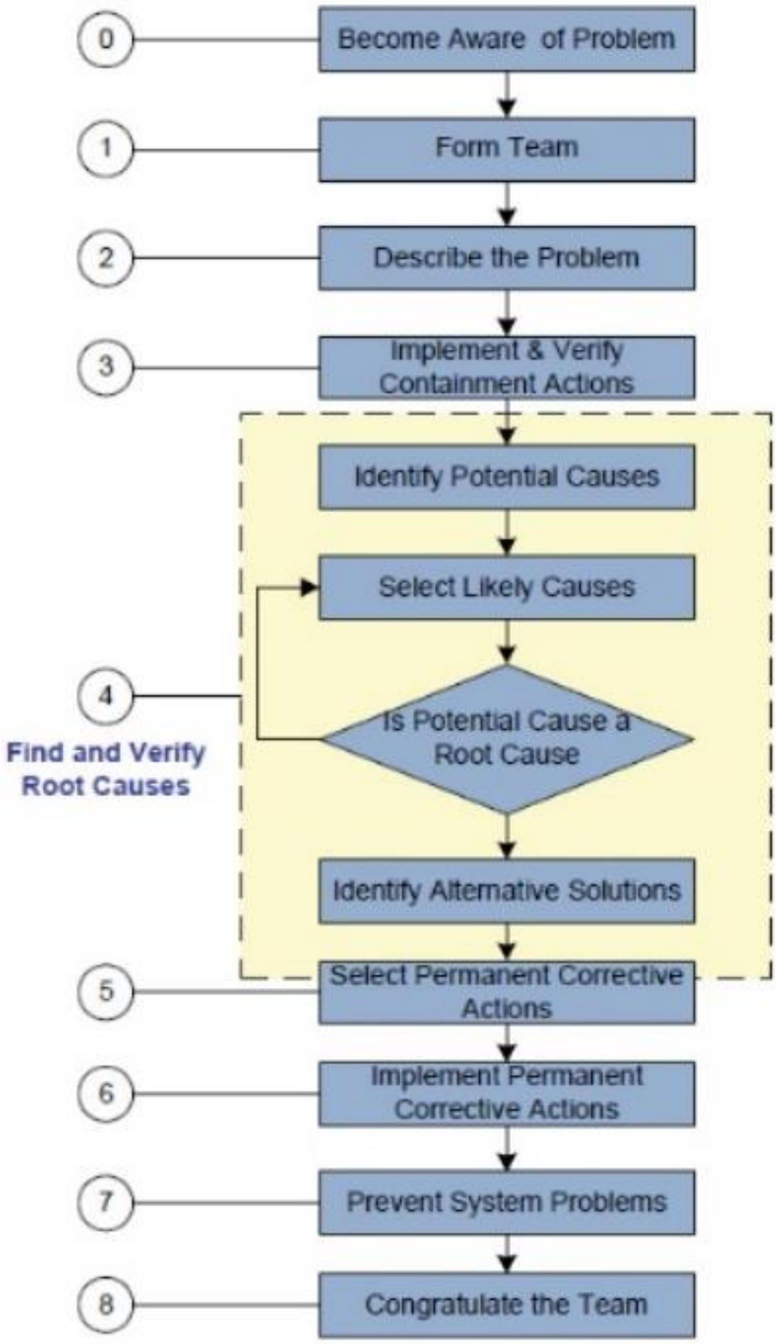


Figure 14 The 8D process (Ford 2000)

The main goal was the identification of errors, the root cause analysis, the limitation of waste, the prevention of fault reoccurrence, cost reduction in production and a general rise in quality. Krajnc (2012) review of the 8D method highlights that the problem definition phase can be described as follows: ‘When describing the problem, the 5W+2H method should be used, where the following questions have to be answered thoroughly and systematically: Who, What, Where, When, How, How many/much, and Why for each question. The answers to these questions help us clarify the background and connections.'

2.3.2.5 Six Sigma

Eckes (2001) writes that in the late 1980's, the concept of Six Sigma was developed in Motorola by Bill Smith. This concept was developed by an engineer and statistician, Mikel Harry, using the principles of Deming's concept of process variation. During the development of Six Sigma in 1983, Harry did work with Dorian Shannin. In the same timeframe, Harry was completing work on the Logic Filters shown in Figure 15. This framework was adopted by Motorola.

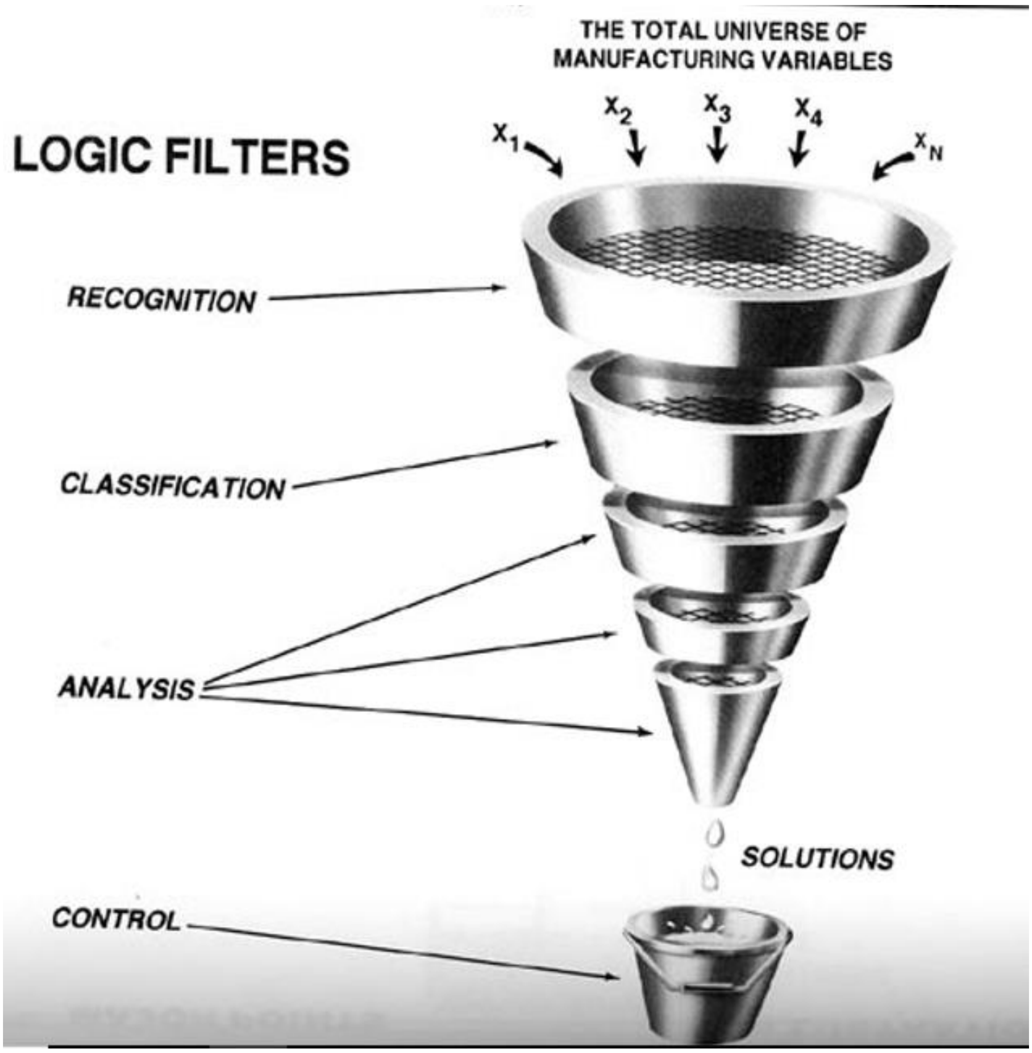


Figure 15: The Logic Filters (Harry 1983)

From 1986, the quality target of 3.4 parts per million (ppm) defects (a defect is defined as something not meeting the customer's requirement) was adopted for all processes across the business. Figure 16 provides the visualization of the Six Sigma approach,

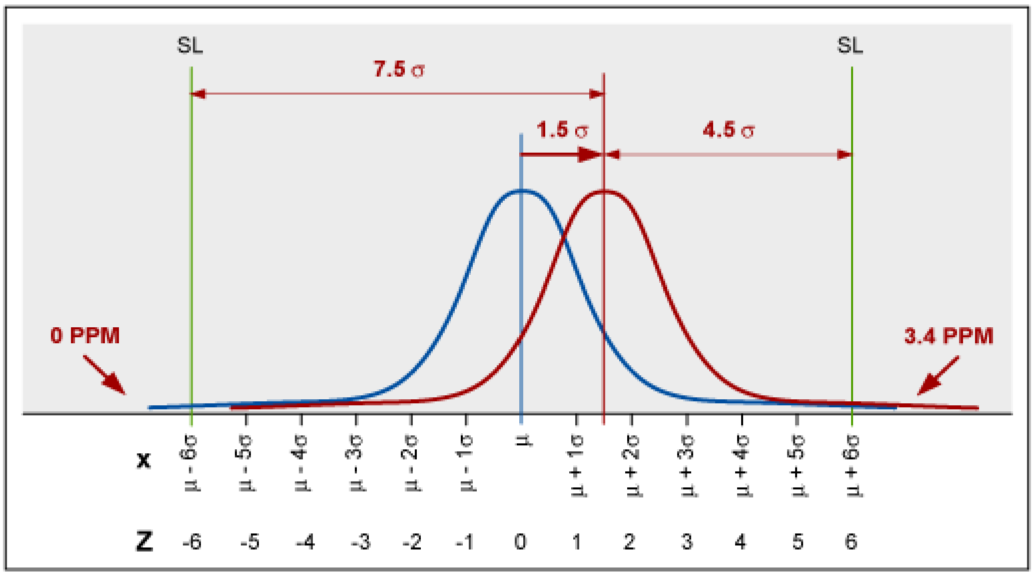


Figure 16: The definition of Six Sigma (isixsigma 2017)

The structure called DMAIC which stands for Define, Measure, Analysis, Improve and Control was used for structuring problem solving. The purpose of the Six Sigma DMAIC methodology was to resolve problems with unidentified answers. The issue or ("Y") must be well-defined in tangible, quantifiable terms with a working description, from the "X" which were the 'universe of all manufacturing variables' seen at the top of the Logic Filters. Pande et al (2000) describe the process as the need to create a process map and a cause and effect diagram. They suggest that a tool to gather group ideas was a 'structured brainstorm' and then the ideas are populated on the cause and effect structure. Another technique used to define the "Y" is the Cause and Effect Matrix. The method involves listing all the variables important to the customer and then listing all the Key Input Process Variables (KIPV) obtained from a structured brainstorming. Following this process, a ranking scale is used to grade the KIPV's. This process is subjective and does not cover the scope of problem definition, but undertakes a form of risk assessment against customer wishes. A review of training material for GE, Ford and Motorola all show the same approach to problem definition as using structured brainstorming and the Cause and Effect Matrix. Evidence shows wide spread use of this approach still and is discussed later in this section. Figure 17 shows the DMAIC process.

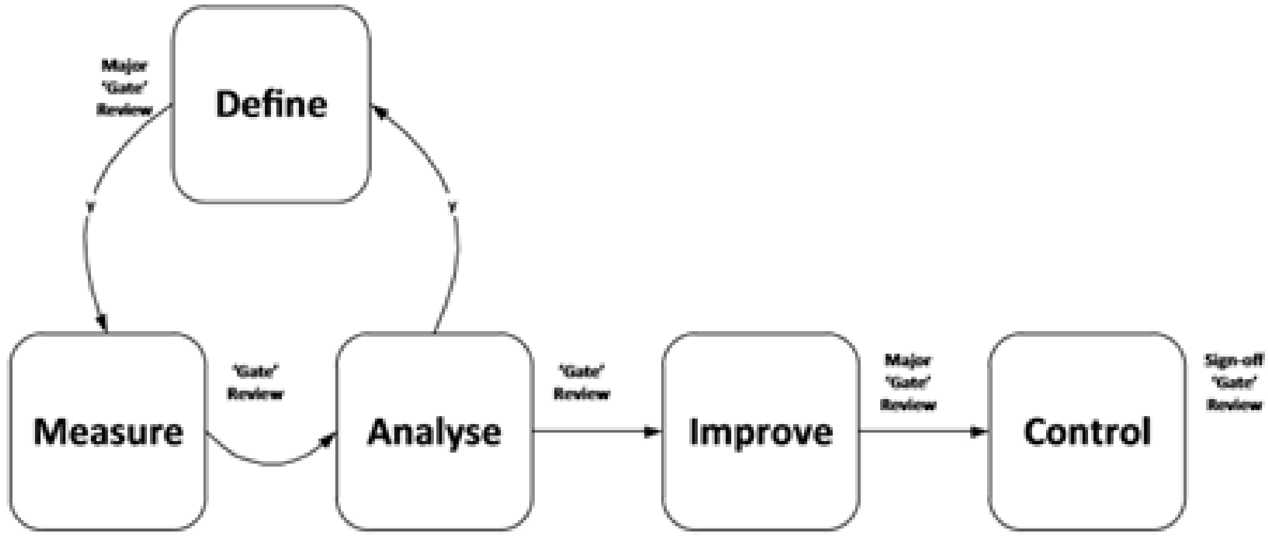


Figure 17 The DMAIC gated process (source ISO13053-1)

Linderman et al (2003) describe the origin of Six Sigma as Motorola's quality goal of 3.4ppm (parts per million) defects within a process critical to customers. Harry (2000) one of those responsible for the development of Six Sigma, describes the method of Six Sigma, as for the improvement of organisational processes that goes beyond quality assurance or quality control. Harry (2006) clarified his view of Six Sigma explaining that, 'people forget that Six Sigma is not an absolute; it's a vision', 'Six Sigma relies on tools' and that 'Six Sigma is simply an umbrella and sitting under that umbrella are many types of tools and practices'. Gutierrez et al (2012) in their review of literature on Six Sigma, considered it a management philosophy, highlighting that the methodology, was like the concept of Total Quality Management (TQM) and cite Lucas (2002), Green (2006), Llorens and Molina (2006), Van Iwaarden et al. (2008) and Cheng (2009) who also support this view of Six Sigma. In a more recent definition from within Motorola, Liu et al (2013) summarises the Motorola philosophies of Six Sigma as Customer first, People are the most valuable resource, Continuous improvement and 'Gemba' focus. Gutierrez et al (2012) claim the Six Sigma methodology is becoming one of the most successful quality management initiatives. They cite Motorola and General Electric as providing the best-known examples of Six Sigma success.

With respect to cost saving associated with the implementation of Six Sigma, the following was given as a summary from the literature. Harry (1998), involved in the initial design of Six Sigma claimed that using Six Sigma could save about 6% cost reduction each year, this was in the late 20^{th} Century. Hann et al. (1999) highlight that General Electric obtained savings of over 940 million dollars in three years. Lucier and Seshadri (2001) find that Motorola increased its operating margin from 14.4 to 18.4% during the first five years of programme implementation. Snee and Hoerl (2004) concluded that 'Six Sigma initiatives typically return 2 to 4% of sales to the bottom line in the second and third years for small companies and 1 to 2% of sales in the same period for large companies'. The Bovarnick (2006) study of uses of Six Sigma in Fortune 500 companies implementing (Lean) Six Sigma spent about 0.6% of revenue on Six Sigma and get obtained $8 return for every dollar they spend on the programme. Pulakanam (2012) concludes that Six Sigma has many tangible and intangible benefits including improved customer satisfaction and increased stock price. The overall benefits of pursuing quality, be it TQM or Six Sigma, far outweigh the costs. This view on stock price is counter to Goh et al. (2003);their earlier study of stock price performance of companies using Six Sigma highlighted that there was no significant difference in stock price performance on the announcement day or in the long run from the use of Six Sigma. They argued that Six Sigma has a weak impact on stock performance. This was no surprise based on the further research of Pulakanam (2012) who concludes that the cumulative savings, as a percentage of revenues ranged from 0.02 % to 6.8 %, with an average of 1.7 %. This equates to a direct saving of $1 to $2 million a year for the period of implementation, with effective implementation into a $100 million organization. The best-case scenario was therefore $6.8 million a year savings, which was unlikely to cause a large stock movement in such an organization. This measurement of stock value appears to act as a deviation, although important, it was perhaps better to consider the value of Six Sigma in terms of its outcome, which was a project after training. (The standard approach for Six Sigma implementation is to teach a selection of employees and they then complete a project within the company.) A view supported by Shamji (2005), who studied several firms' experiences, including those of Samsung Electronics, American Express and DuPont and observed that the savings related to each Six Sigma improvement project ranged from $100,000 to $200,000. In support of this, Pulakanam's (2012) research found that typical Six Sigma programmes run for three to four years, producing minimal savings in the first year, due to training costs and the time required to start the initial projects, which in turn leads to the benefits in the latter years of the programme. The research was mainly undertaken on large USA companies where data was available. This view was supported by Montgomery (2004), who considers projects as the primary vehicle used to drive improvements in quality and productivity in Six Sigma. Furthermore, Six Sigma's impressive bottom-line results normally flow from successful completion of Six Sigma projects. In an article in Quality (2012) the following was written about Six Sigma. 'The results certainly didn't come overnight. But the results were no accident, either. The individuals and teams involved used skill sets developed in Six Sigma training programs. Six Sigma training is an investment in time and money. It allows you to identify your opportunities for improvement, to improve your processes, and to save money. Miracles no, results, yes.' Schroeder et al. (2008) defined the Six Sigma tools and techniques as appearing to be like prior quality management approaches, but that Six Sigma provides an organisational structure not previously seen, hence, the belief that Six Sigma was a totally new paradigm for quality improvement.

2.3.2.6 TRIZ

The Russian phrase 'Teorija Rezhenija Izobreta-telskih Zadach' (TRIZ), is a Russian acronym for The Theory of Inventive Problem Solving. TRIZ was developed by Genrich Saulovich Altshuller (1926–1998) (Domb 2002). Altshuller was a Russian scientist and engineer, who with his colleagues, analysed approximately 400,000 technology patents [Domb 2002). This study allowed them to draw patterns which governed the process of problem solving and innovation. Innovation is a later development as the original intent was for technology-related problems. Rantanen and Domb (2002) explored the principles of TRIZ and explain that the idea involves an object and a tool and a contradiction which occurs when the object and the tool are used together. The aim of TRIZ is to define the contradiction and then solve this problem. Savranksy (2000) described TRIZ as a knowledge-based systematic methodology of inventive problem solving. Fey and Rivin (2005) described TRIZ as a methodology for the effective development of new [technical] systems, in addition to TRIZ being a set of principles that describe how technologies and systems evolve. Also, it has been described by Gadd (2011) as a toolkit consisting of methods which cover all aspects of problem understanding and solving. Livotov (2008) regards the TRIZ toolkit as one of the most comprehensive, systematically organised for invention and creative thinking methodology known to man. Souchkov (1997) describes TRIZ as resting on the premise of technology evolution and Eversheim (2009) adds that TRIZ is the way to invention and is not a random process, but is predictable and governed by certain laws. This is supported by Savranksy (2000) who writes that TRIZ was an analytical logic and a systematic way of thinking. TRIZ has been described in various ways – a methodology, a toolkit, a science (Barry et al., 2006), a philosophy (Nakagawa, 2001), and with such a wide description, this could potentially create confusion as to what TRIZ was, and therefore what TRIZ can achieve remains unclear. However, TRIZ does possess considerable advantage over other methods applied to problem solving and innovation.

Methods such as brainstorming, mind mapping, lateral thinking and morphological analysis, can identify or uncover a problem and its root cause by using the patterns established from the original research of patents. However, the lack of capability to point out solutions to the problem relies on the user's knowledge of TRIZ and the problem which was being solved. Gadd's (2011) view was that TRIZ helps to identify problems and offers direct solutions to them, along with confidence that most (if not all) possible new solutions to the problem have been considered. Furthermore, Gadd (2011) believes that central to TRIZ was the set of conceptual solutions to technical problems. This set of solutions was a collection of the inventive principles, trends of technical evolution and standard solutions as provided by TRIZ. In its conceptual form, the problem can then be matched with one or more of the conceptual solutions. The identified conceptual solution can afterwards be transformed into a specific, factual solution that answers to the original factual problem. Ezickson (2005) and Souchkoy (2008) both feel that overall TRIZ is viewed as complex methodology by many people. Russian TRIZ scholars view the current trend of simplification as watered down TRIZ. Many examples of the use of TRIZ combine another method, for example Six Sigma, with the application of TRIZ which supports the simplification theory. Review of TRIZ application reveals that the use of pure TRIZ was rare and that the application tends to be as part of a more general approach, a technique to use if we get stuck or in the field of creativity.

For completeness, how to apply TRIZ for problem solving was included. Figure 18 provides a visualization of the TRIZ concept for problem solving.

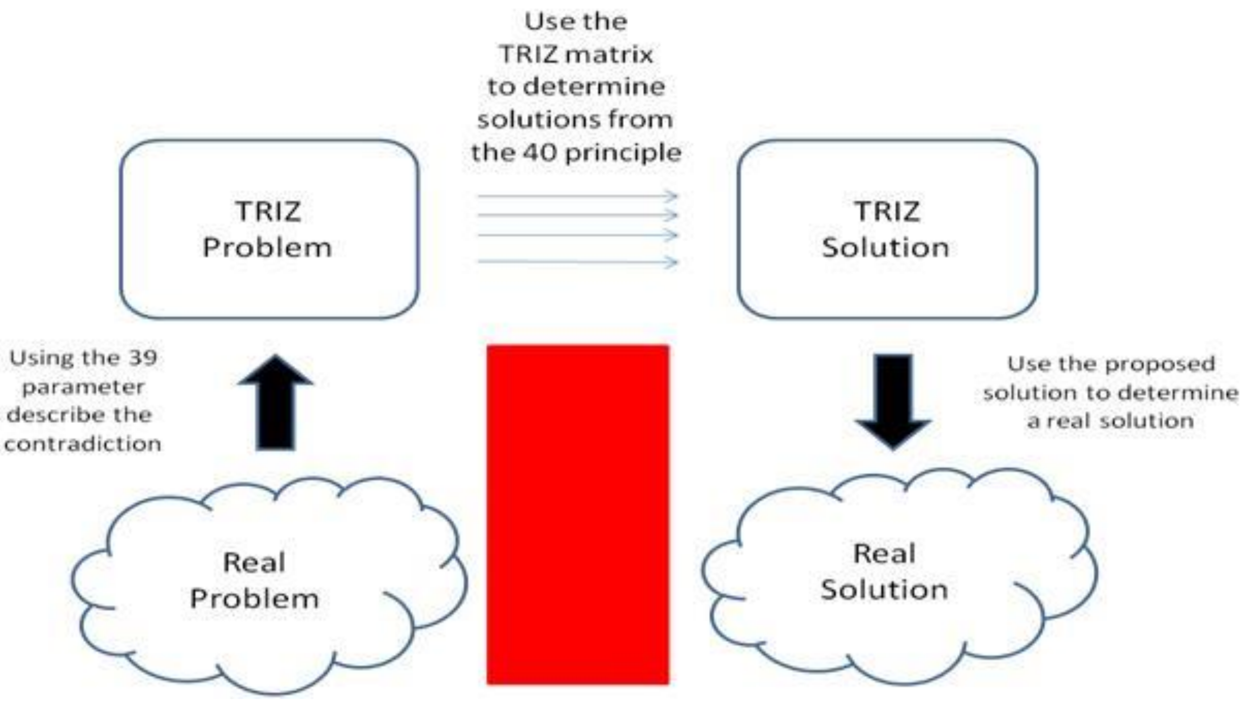


Figure 18 The TRIZ model (after Smyth-Renshaw)

To use TRIZ, the following process steps should be followed: -

1. Select the product or service which requires improvement

2. Breakdown the product/service to a specific part which requires improvement

3. Select a particular function of that specific part of the product/service

4. Propose a method which you believe will improve this particular function.

5. Propose the negative effect of the improvement, this is the contradiction.

6. Write a statement about the contradiction 'Taking this action will improve function Z in this way, but will cause function X to get worse'

7. Now fit this statement to the matrix, explore TRIZ solutions using brainstorming.

8. Repeat as necessary addressing all contradiction.

The technique defines 39 states/conditions for the objects and the tools and using these a 'real' problem can be defined as a 'TRIZ' problem. There are also 40 principles which are used as the general solutions. These are shown in Figure 19 below.

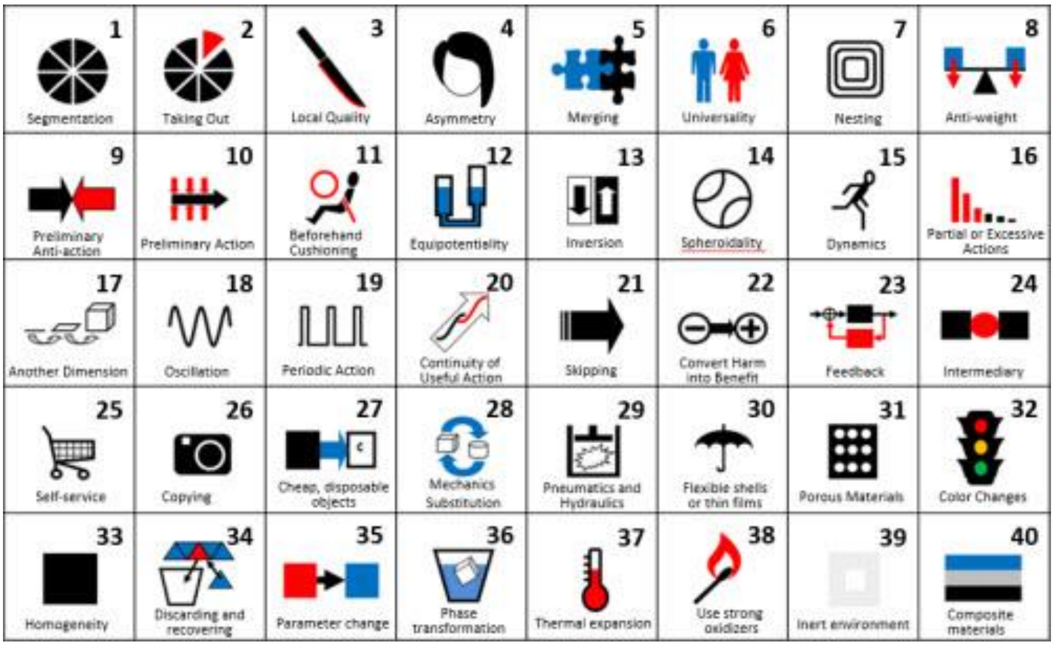


Figure 19: The TRIZ 40 solution (triz-journal 2017)

A small abstract of the TRIZ matrix and its application was given in Figure 20. In this example, a real-life problem has been transformed into a TRIZ problem in which the improving parameter was 'area of the moving object' and the worse parameter was the 'weight of moving object'. Using the intersection of the TRIZ matrix the number 2, 17, 29, 4 are found. These numbers are reference to the TRIZ general solutions. The user must now link these general solutions to a real solution which solves the initial real problem.

Getting Worse / Getting Better	1. Weight of moving object
5. Area of the moving object	2 17 29 4

Figure 20: The TRIZ matrix in use (after Smyth-Renshaw)

Examples of where TRIZ has been used are available and several examples are given to explore the benefits and shortcomings of the TRIZ approach. Petrovic et al (2014) used the TRIZ method in an application of vehicle maintenance and the solution obtained was a quarter of the cost of the old solution. The use of SPC (Statistical Process Control) and Pareto analysis in a Six Sigma context were used to identify the problem, but TRIZ provided the solution.

Furthermore, the success of the application lay in the ability of the user to properly interpret the instructions recommended by TRIZ. Petkovi et al (2013) highlights the use of TRIZ in the development of innovative design for a passive compliant robotic joint. One drawback seen in this research was the rapidity of use from concept to design due to the application of knowledge required. This was balanced as designers using TRIZ, proposed quicker solutions than the other methods which focused on creativity, stimulation and innovation. Moreover, the use of TRIZ gives designers a route to express their creativity. Wang and Chen (2010) applied TRIZ within a Six Sigma DMAIC project and the case study shows a cost saving of $828,000 (but without a percentage of saving against turnover). The Banking project successfully eliminates the waste of waiting time for opening an account, modifies business cultures and creates the infrastructure to initiate and sustain greater performance and profitability.

2.4 Other Frameworks with limited academic research

2.4.1 Introduction

This section includes those frameworks with no or little academic research. The description of each approach has been taken from various sources including training material. The inclusion of this section was to acknowledge the existence of frameworks which were used within the scope of this research, but that for some reason had not been subject to no/little formal academic research.

2.4.2.1 '5 step problem solving' pentagon

Kanji & Asher (1993) presented a model for problem solving as shown in Figure 21. The model described as 'a logical sequence for solving problems', 'guide to identifying which tools and techniques to apply' and the model 'can be applied to any problem or deviation from requirements.' Further guidance was provided, a decision rule at the end of each stage, that was 'if at the end of each step the output does not match the requirement, you should review the activities within the step.' Furthermore, Kanji & Asher cited the work of Kane (1989) and they claim the model in Figure 21 was like other models of that period.

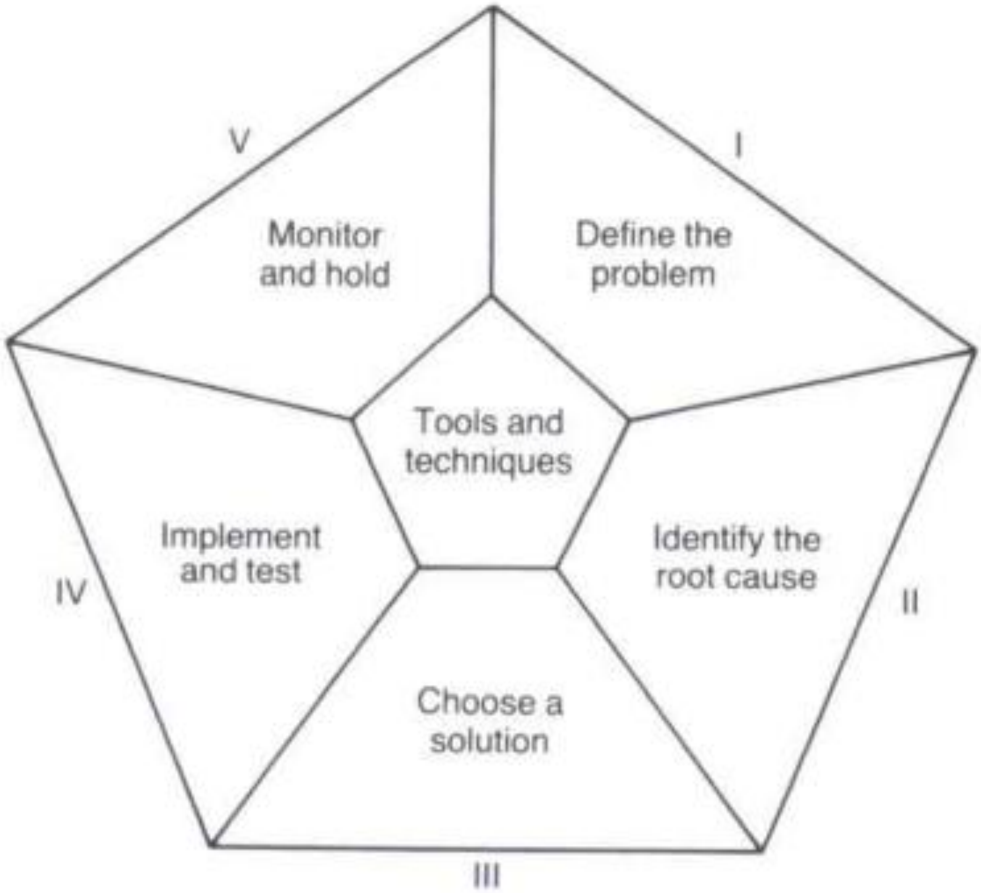


Figure 21 5 step problem solving pentagon (Kanji & Asher 1993)

The centre of the pentagon was the tools and techniques used within each step of the model. Although tools and techniques have been reviewed within the next section of the chapter, for this model, the tools and techniques have been considered as part of this review, as the model was an interesting approach which conflicts with the tools and techniques used. Kanji & Asher describe the problem-solving process needed ‘to generate plenty of possible root causes and solutions and to use data to select the options’. Figure 22 provides a list of the tools and techniques, which are the 7QC tools as given by Ishikawa and used as part of the PDCA cycle given earlier in the chapter.

	Problem-solving process				
	1	2	3	4	5
Brainstorming	✓	✓	✓	✓	✓
Cause and effect	✓	✓	✓	✓	
Pareto analysis	✓		✓		
Checksheets		✓	✓		
Histograms	✓		✓		
Scatter diagrams			✓		✓
Concentration diagrams			✓		

Figure 22 Tools and techniques used in the 5-step model

This model was considered further in Chapter 4.

2.4.2.2 Military version of brainstorming – Appreciation Process

The Australia military has developed a process for problem solving; this was called the Appreciation Process (LWD 5-1-4) (2012). The process was defined as a five-step process

1. Define the problem – using the 5W1H method – that was; what, why, where, when, who and how of the problem
    a. What exactly is the problem you are trying to solve – was there, in fact, a problem? Write it down in specific terms so that it can be clearly understood.
    b. Why was it a problem?
    c. Who else was impacted by the problem, or needs to be involved?
    d. When do you need to solve this problem? How long have you got?
    e. Where was the root of the problem? Or what was the root of the problem?
    f. How do you feel about the problem?
2. Examine the facts – what are the factors that influence how you solve this problem – lack of resources, time or money? Each factor was examined to determine exactly what each one really means to your problem, and you can do this simply by asking the question – 'so what?' after each factor. This process was repeated until there was no more 'so what's?'
3. Brainstorm options – once you have a thorough understanding of all the facts, and what this really means – you can start brainstorming options for solving your problem.
4. Determine approach.
5. Implement solution.

There was no academic research on this technique, during the literature review it was discovered during the literature review search of the internet and was included for completeness of research.

2.4.2.3 Why because analysis

Why Because Analysis (WBA) has been used in accident investigation (Ladkin and Loer, 1998). The roots of the method can be traced back to the 1770's when, David Hume proposed the Counterfactual Test (Stanford). Counterfactual Test determines rigorously whether event A was a necessary causal factor in the occurrence of event B. This was formulated into modern formal logic (Lewis 1973). In the current form, WBA starts with the question "What is the accident or accidents in question?" In most cases this was easy to define. The next phase was, by using an iterative process, try to determine causes. When causes for the accident have been identified, formal tests are applied to all potential cause-effect relations. So just looking at the problem statement, it was a one-line statement of fact, for example, the plane crashed into the hill. Ladkin and Loer (2001) detail the use of the method with respect to several airline accidents. As in the previous section there was no academic research as to use of the method was found and it was included for completeness. Figure 23 shows the structure for the Herald of Free Enterprise accident in 1987.

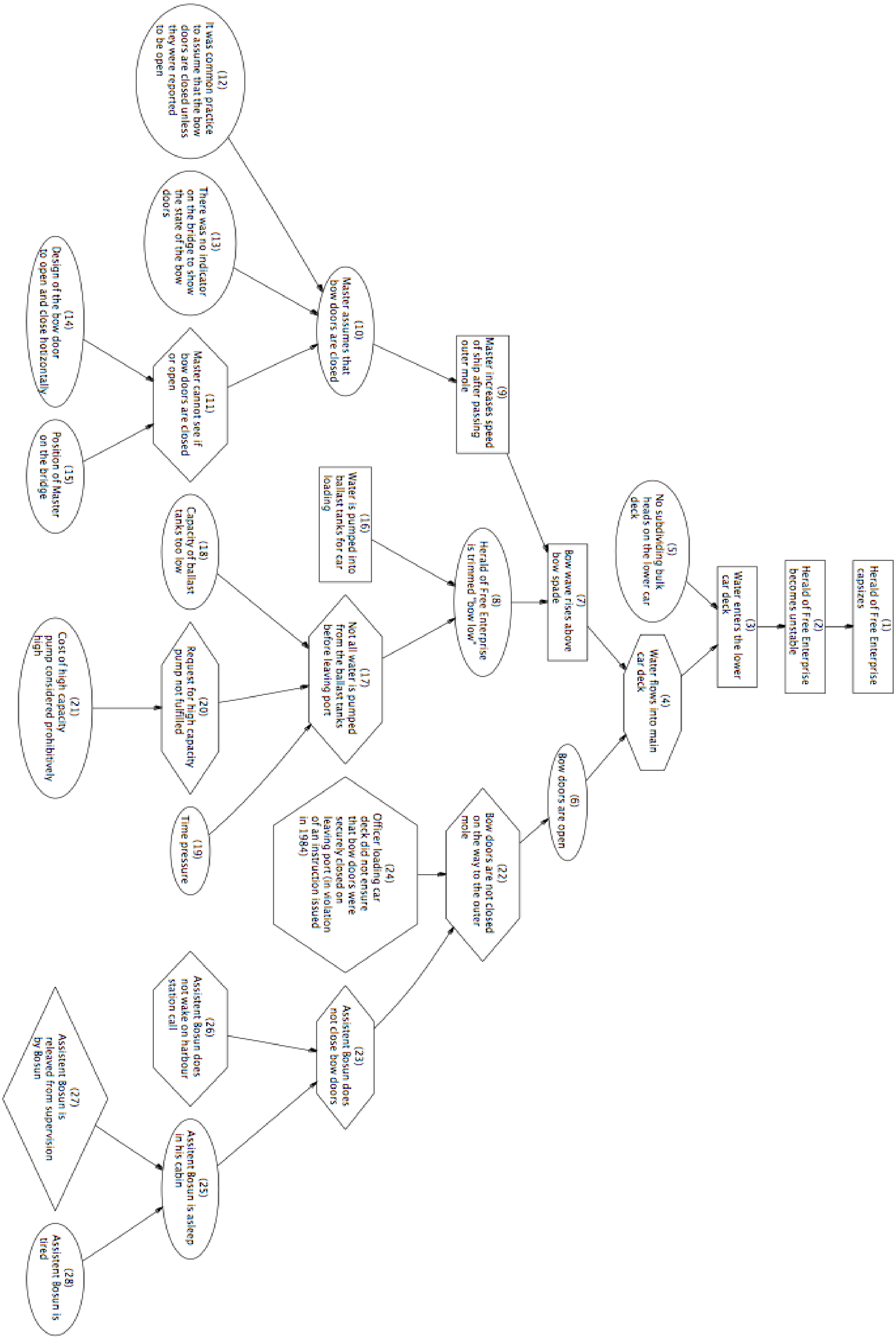


Figure 23: The Why Because Analysis structure (Ladkin and Loer)

2.4.2.4 Shainin

Dorin Shainin, developed his approach to problem solving in the mid-20th Century, the Shainin System (1993). The use of Shainin methods was difficult to research as the technique and approach was copyrighted and protected via the courts if a word was used out of context and without the official training. However, from the material available the following summary of the technique has been drawn. The purpose of the first stage of the system was to quantify the magnitude of the selected problem. To help define the project the process output was monitored using an appropriate sampling scheme for a sufficiently long period of time, so that the effect of all causes of variation, especially the dominant causes are seen. The process variation was then displayed using a histogram or summarised numerically. The baseline distribution was used to quantify the problem, to set a goal that has the potential to improve the process, and to assess any proposed remedy. The baseline distribution was also used to plan and check that a dominant cause exhibited its full effect in each investigation in the progressive search. This was important information necessary to keep the user from focusing on the wrong family of causes. The idea of quantifying the nature of the problem was part of all problem-solving approaches. The unusual feature of the Shainin System was the explicit link between the search for the dominant cause and the baseline distribution. Furthermore, Shainin (1993) states, 'there is no place for subjective methods such as brainstorming or fish bone diagrams in serious problem solving.' Examples where the approach has been used are difficult to obtain, for the reasons given earlier. It was difficult to review the use and application of Shainin. Steiner et al. (2008) support this value? and concluded that much of the Shainin approach was not well documented or adequately discussed in peer reviewed journals. Shainin also worked with Harry (Harry 2017) in the 1980's prior to the development of Six Sigma. Figure 24 shows the Shainin structure.

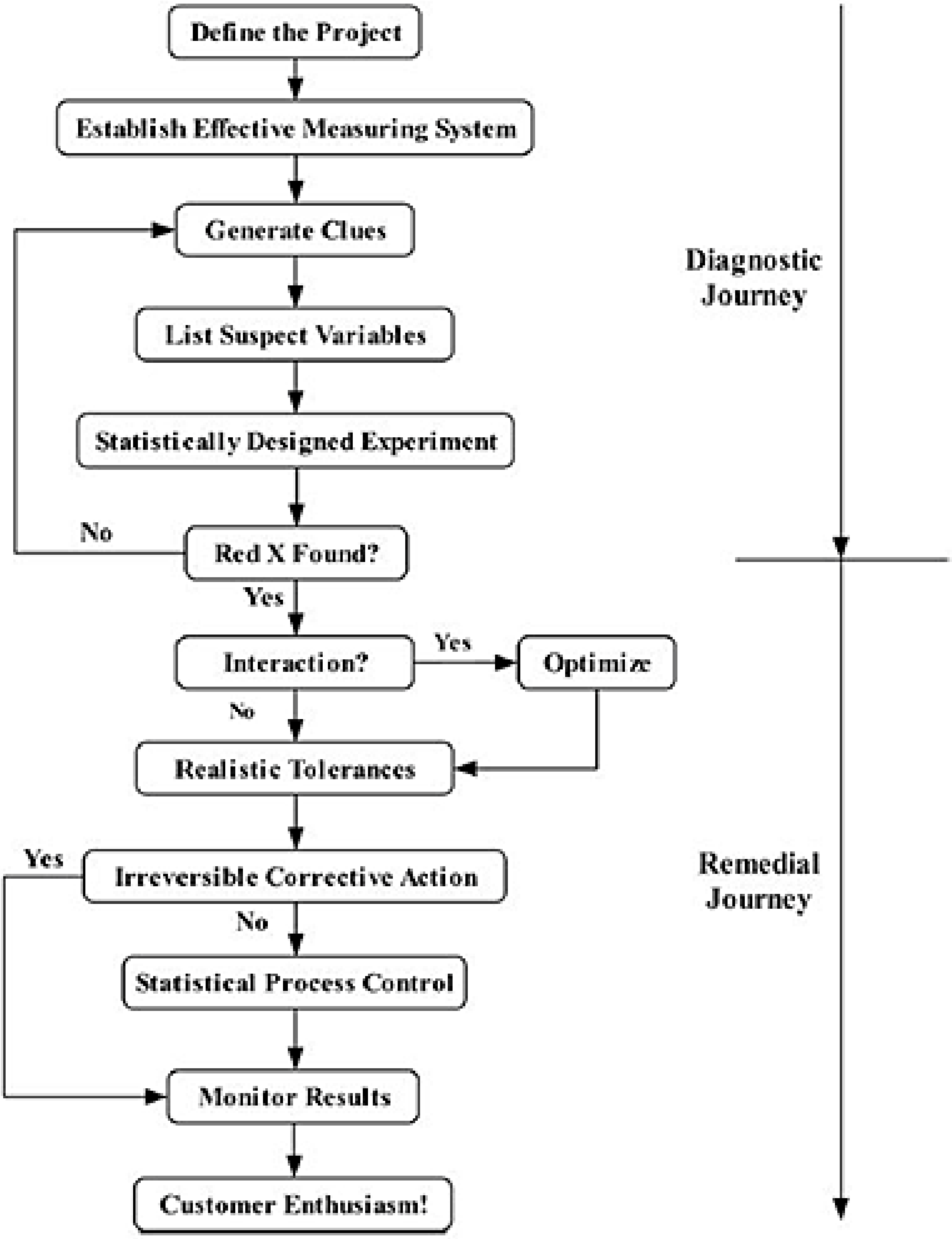


Figure 24 The Shainin system for quality improvement (Shainin, 1992)

2.4.3.5 Kepner - Tregoe

The Kepner-Tregoe method was defined as a four-step process: define and describe the problem, establish possible causes, test the most probable cause, and verify the true cause. (Marquis, 2010). The define and describe the problem phase uses a technique of questioning called ‘Is and Is not’ against a set of criteria - What, Where, When and Extent. Following this process, a problem statement was determined. Britz, Emerling, et al (2000) and Hoerl and Snee (2002) describe the ‘Is and Is Not’ Analysis which helps narrow the search for a root cause. The analysis documents what, where, when and extent associated with the problem and those not associated with the problem symptoms. Using the training material for Kepner-Tregoe (Kepner-Tregoe 2010), the process was detailed as follows

The Problem Analysis process divides decision-making into five steps:

1. Define the Problem
2. Describe the Problem
3. Establish possible causes
4. Test the most probable cause
5. Verify the true cause

Defining the Problem

Problem Analysis begins with defining the problem. This step was a critical step as failure to understand exactly what the issue was results in wasting time. The problem definition will include more information. A good model for clarifying statements was the Goal Question Metric (GQM) method. The result was a statement with a clear Object, Purpose, Focus, Environment, and Viewpoint. In developing a problem definition, the "5 Whys technique" was used to arrive at the point where there was no explanation for the problem. Using 5 Whys with Kepner-Tregoe only accelerates the process.

Describing the Problem

With a clear problem definition, the next step was to describe the problem in detail. The four aspects of any problem: what it is, where it occurs, when it occurred, and the extent to which it occurred. The IS column was used to describe specifics about the problem -- what the problem IS. The COULD BE but IS NOT column was used to list related but excluded specifics -- what the problem COULD BE but IS NOT. These two columns aid in eliminating "intuitive but incorrect" assumptions about the problem. The differences between the IS and COULD BE but IS NOT. These differences form the basis of the troubleshooting.

Establish Possible Causes

In this step time was spent to examine "what has changed since it worked" and checking for changes. As many changes, can occur, the Problem Analysis was used to describe what the problem is and what the problem could be, but is not.

Test the Most Probable Cause

With a short list of possible causes (recent changes evaluated and turned into a list), the next step was to think-through each possible problem, by asking the following question.

"If ____ is the root cause of this problem does it explain the problem IS and what the problem COULD BE but IS NOT?"

If the potential solution was the root cause, then the potential solution must "map to" or "fit into" all the aspects of the Problem Analysis.

Verify the True Cause

The next step was to compare the possible root causes against the problem description. Eliminate possible solutions that cannot explain the situation, and focus on the remaining items. Before making any changes, verify that the proposed solution was the root cause. Failure to verify the true cause invalidates the entire exercise and is no better than guessing. After verifying the true cause, the action required repair the problem are undertaken.

2.4.3 Summary of the Frameworks

Table 3 provides an overview of the frameworks detailed within the previous sections of the chapter.

Frameworks	**Who**	**When**	**Use**	**Further comment**
Shewhart cycle	Shewhart	1939	Initial Improvement approach	
PDSA cycle	Deming	1993	Widespread (other frameworks can be traced to PDSA cycle)	Developed from Shewhart
PDCA cycle	Japanese executives	1950	Kaizen	Developed from Deming
Kaizen	Ohno	1978	TPS and wide spread across the globe?	Used as part of TPS and therefore copied by companies following the TPS approach
A3	Toyota Motor Company	1960	Widespread across many businesses	"define" (Liker & Meier 2006) "method" (Sobek & Smalley 2008) (Matthews 2011) "application in health care (Ghosh 2012)
Global 8D	Ford Motor Company	1990	Initial automotive but wider application in industry	"review of ...." (Krainc 2012) "defines" Wright (1995)
Six Sigma	Motorola	1985	Widespread across many businesses	"beyond quality assurance and quality control" (Harry 2000) "similar to Total Quality Management" (Gutieriez et al 2012) "benefits of ...." (Lucier & Seshadri 2000) (Snee & Hoeril 2004) (Bovarnick 2006) "issues with ...." (Goh et al 2003) "programme" (Pulakanam 2012) "structure of ....." (Pande et al 2000) Eckes (2001)

TRIZ	Altshuller	1950	Comprehensive method Used within Six Sigma	"define" (Savranksy 2000) (Fey & Rivin 2005) (Gadd 2011) (Souchkov 1997) "application of ....." (with Six Sigma project (Wang & Chen 2010)) (design of robotic joint (Petkovi et al 2013) (Vehicle maintenance (Petrovic et al 2014))
5 step pentagon problem solving model	Kanji & Asher	1993	Case studies by the author	"model" Kanji & Asher (1993)
The Military Version				For completeness of research
Why because analysis based on causation theory	Lewis (Ladkin & Loet)	1973	Accident investigation	"define use" (Ladkin & Loet 1998)
Shainin				Copyrighted techniques (No further research can be undertaken due to copyright)
Kepner – Tregoe	Kepner & Tregoe	1950	Widespread across many businesses	"analysis of ... " (Britz, Emerling et al 2000) (Hoerl & Snee 2012)

Table 3: A summary of the Frameworks for quality problem solving

For each framework, there are unique steps and tasks to undertake in the completion of the framework. The steps for each framework are detailed in Table 4.

Frameworks	PDSA	Japanese PDCA	Appreciation process (LWD 5-1-4)	Why because analysis (WBA)	Shainin
Additional Comments	Academic research available	Academic research available	No academic research	No academic research	Copyrighted
Process steps	Plan * Objective * Questions and predictions * Plan to carry out the cycle (who, what, where, when)	Plan * Determine goals and targets * Determine methods of reaching goals	1. Define the problem (using 5W (why) & 1H)	1. What is the accident?	1. Define the project
			2. Examine the facts	2. List possible causes	2. Establish effective measuring system
	Do * Carry out the plan * Document problems and unexpected observations * Begin data analysis	Do * Engage in eductin and training * Implement work	3. Brainstorm options	3. Formal tests to determine cause & effect	3.Generate Clues
	Study * Complete the data analysis * Complete data to predictions * Summarize what was learned?	Check * Check the effects of implementation	4. Determine approach		4. List suspect variables
	Act * What changes are to be made? * Next cycle?	Act * Take appropriate actions	5.Implement solutions		5. Statistically designed experiments
					6. Red X found?
					7. Interactions?
					8. Realistic tolerances
					9. Irreversible corrective action
					10. SPC
					11. Monitor results

Frameworks	Global 8D	K-T process for problem analysis	Six Sigma	A3	TRIZ
Additional Comments	Academic research available	No academic research	Academic research available	Academic research available	Academic research available
Process steps	1. Become aware of problem	1. Define problem	1. Define Decision gate	1. Initial problem perception	1. Select the product or service which requires improvement
	2. Form team	2. Specify problem	2. Measure Decision gate	2 .Clarify the problem	2. Breakdown the product/service to a specific part which requires improvement
	3. Describe the problem	3. Identify differences and changes	3. Analyse Decision gate	3. Locate area/point of cause	3. Select a particular function of that specific part of the product/service
	4. Implement & verify containment actions	4. Formulate causes	4. Improve Decision gate	4. 5why? Investigation of root cause	4. Propose a method which you believe will improve this particular function.
	5. Identify potential causes	5. Test cause against the facts	5. Control	5. Countermeasure	5. Propose the negative effect of the improvement, this is the contradiction.
	6. Select likely causes	6. Prove true cause		6. Evaluate	6. Write a statement about the contradiction 'Taking this action will improve function Z in this way, but will cause function X to get worse'
	7. Is potential cause a root cause?			7. Standardize	7. Now fit this statement to the matrix, explore TRIZ solutions using brainstorming.
	8. Identify alternate solutions				8. Repeat as necessary addressing all contradiction.
	9. Select permanent corrective actions				
	10. Implement permanent corrective actions				
	11. Prevent system problems				
	12. Congratulate the Team				

Table 4: The detail for each framework from the research (reference from each section)

This section of the chapter has provided a review of the frameworks used to investigate quality problems within business. Using the model developed by Weckenmann et al 2015, the frameworks reviewed address 'failures' within the operation of the model. The section has split the frameworks into two groups: those with and without (or very little) academic appraisal. The objective of the section was to demonstrate the frameworks' structure (the process and tools/techniques used), determine the application and benefits derived from using the framework. Further to this, it was important to consider the business benefits achieved from the application of the various framework. Although, it was not possible to determine an exact figure for each of the frameworks, there was evidence that Kaizen was at the heart of problem solving in Toyota, the Global Automotive Group (Womack et al, 1990, Liker, 2004) together with A3 (Sobek and Smalley, 2008). Global 8D was widely used by Ford, another Global Automotive Group (Smith, 2005). However, Smith (2005) also observes that Ford was also using Six Sigma. There was a significant amount of data as to the benefits or not of Six Sigma, positive, Bovarnick (2006) citing a return of $8 return for each dollar spend in Fortune 500 companies and negative, Goh et al (2003) who highlighted that there was no significant change in stock price. However, Pulakanam (2012) provided an explanation for this outcome and concluded that a $100 million organization could expect a best-case return of $6.8 million a year saving.

The frameworks are the process of moving from a problem to a solution in a cost effective and timely manner. Within the steps of the frameworks, various tools and techniques are used to formally describe the problem to be solved and possible root causes of the problem. These are considered in the next section.

2.5 Tools and Techniques used within the frameworks

2.5.1 Introduction

Within this section, it was the tools and techniques used within the framework which have been reviewed, in many cases the same tools; techniques are used across multiple frameworks. The rationale for which tools and techniques to be review was considered, only those which have been used with frameworks with academic reviews to capture information about the quality problem, be that factual, opinions and guesses, have been reviewed. TRIZ was not considered further as TRIZ was developed using an empirical method, which was outside the scope of this research. TRIZ has been included to acknowledge existence of the framework. Furthermore, the order of the review was such that tools and techniques which attempt to define the problem are reviewed prior to those which attempt to capture the collective views as to the cause and effect linked to the quality problem. The 5 why technique was also considered as the technique was widely used in quality problem solving. Graphical techniques, such as Pareto Charts, Scatter Plots, Statistical Process Control Charts and Histograms have not been considered as these are secondary analysis techniques and require the collection of data to then be translated into a graph. Table 5 details the tools and techniques and the rationale for choice.

Tool/Technique	Rationale for choice
5W&1H	This technique was used in Global 8D, Kaizen & A3
4 Wives and 1 husband	This technique was linked to 5W&1H
Brainstorming	Brainstorming is used to generate ideas. Brainstorming was used across all the frameworks
Cause and Effect diagram (Ishikawa)	Cause and Effect diagram was used across all the frameworks
Cause and Effect matrix	Cause and Effect diagram was used in the Six Sigma framework
5 why	The 5 why technique was used across all the frameworks

Table 5: Tools/Techniques used within the Frameworks with academic reviews

2.5.2 Tools and Techniques

The next sections provide a review of the tools and techniques. The rationale for the order was given in the previous section.

2.5.2.1 The 5W&1H technique

Michlowicz and Karwat (2010) who detail the findings on the application of Total Productive Maintenance (TPM) in a Polish Enterprise, revealed that the 5W and 1H method was used. In this context, the 5W and 1H are the 5 whys and the 1 how, the method describes repetition of a specific question that was, why? five times. The first question concerns the cause of the failure, the next questions are asked to elaborate on responses and to get to know the reason of the problem more thoroughly. After five why questions, it was possible to answer how to solve the problem (how?). Li and Zhang (2007) research into Chinese news documents reveals that news events are usually described by the 5W and 1H, these are detailed as; when, what, who, where, why and how. The aim of the news concerning an event should be to address the 5W and 1H. Wang, Zhang, Ru and Ma (2008) research also uses the same approach to the 5W and 1H method in a study of automatic online news topic. Inagaki, Sugie, Aisu and Ono (1995) study of behaviour-based intention inference for intelligent robots cooperating with human users, used the 5W and 1H method to classify human intention. In this context the 5W and 1H was classified as when, where, who, what, why and how. Park, Park, Lee and Koh (2006) detail the 5W and 1H method as why, what, who, where, when and how in the development of a Dynamic Role Based Access Control (DRBAC) model based on the context for smart services in an intelligent ubiquitous home. The 5W and 1H is again used in this context by Lee and Hwa (2006) for the DRBAC model using a Wireless Sensor Network Module (WSNM) for services in home. Juravich and Bronfenbrenner (2003) describe in their book, 'Out of the ashes: The steelworkers' global campaign at Bridgestone/Firestone', how employees were put through hours of Total Quality Control which included a section on Deming's 5W's and 1H and these are listed as who, what, where, when, why and how. Ke, Guo, Zhang and Gao (2009) detail research on multi-scale terrain representation and terrain analysis and use the 5W and 1H in which the why, what, who, where, when and how are used to generalize the terrain analysis. Meyer (2010) uses the 5W and 1H method described as who, what, where, when, why and how in the education research into reciprocal teaching in middle years. Le, Kashif, Ploix and Dugdale (2010) used the 5W and 1H method (who, when, where, what, why, how) to collect data for a study which was used in simulating inhabitant behaviour to manage energy at home. Two research studies, one from Japan and the other Brazil both in the local language, use the 5W and 1H method. It is possible to read the 5W and 1H in English and both refer to the asking of why. In the context of introducing Six Sigma: A framework for quality management, Chandra and Goh (2002) describe how Six Sigma may be characterized by the common 5W and 1H, and uses why Six Sigma? as one of the questions. A book entitled; 'Identifying waste on the shop floor', written by the Productivity Development Team (2003), details a 5W and 1H sheet with the key concepts for asking why and how. This links with Michlowicz and Karwat use in TPM introduction detailed as the first application of the 5W and 1H method given in this section. A study within a factory in Indonesia detailed by Susetyo (2011) reveals that the 5W and 1 H method was used. In this research, the 5W and 1H method was detailed as; what, where, who, when, why and how. In a different context, the impact of the globalization process of Hip-Hop music in Semarang as a reflection of American pop culture (a case study of Semarang Hip-Hop community), Alfian (2013) uses the 5W and 1H method, which was described as a journalistic questioning approach and details the questions as; what, when, where, who, why and how. Berty (2011) uses the 5W and 1H in a Lean Six Sigma project to reduce cigarette reject rates. The research provides a table of results in which the 5W and 1H are detailed as follows; what – what action is to take, how –specific steps, who –

responsible, when – initial and final dates, where – specific locations and why – justification for implementation.

2.5.2.2 4 Wives and 1 husband

This technique follows on from the previous section and has a link to Kaizen which was detailed in section 2.3.2. This originates from a popular Japanese saying, and it highlights the principle of a questioning technique.

• The 4 Ws (Wives) are What, Where, Why, and When

• The 1 H (Husband) is How.

The 4 Wives and 1 husband technique was developed after the Kipling poem (1902), which was detailed in the “Just So Stories” in his poems of British soldiers in India, and his tales for children. He proposed ‘five Ws and one H’ as an interrogation method in his famous novel "Just So Stories" (1902) within which a poem accompanying the tale of ‘The Elephant's Child’ opens with: ‘I keep six honest serving-men (They taught me all I knew); Their names are What and Why and When and How and Where and Who.’ (Kipling 1902). This is the reason why the ‘five Ws and one H’ problem solving method is also known as the ‘Kipling Method’. According to the principle of five Ws and one H, a comprehensive report can only be formed if there are answers to these questions starting with an interrogative word:

- What is ......?
- Who should do it or who does it?
- When should it be done?
- Where to do it?
- **<u>Why should it be done?</u>**
- How should it be done?

To provide a full picture of the use of 5W and 1H in the context of Kaizen. The technique of primary and secondary questions was presented. This is shown in Figure 26.

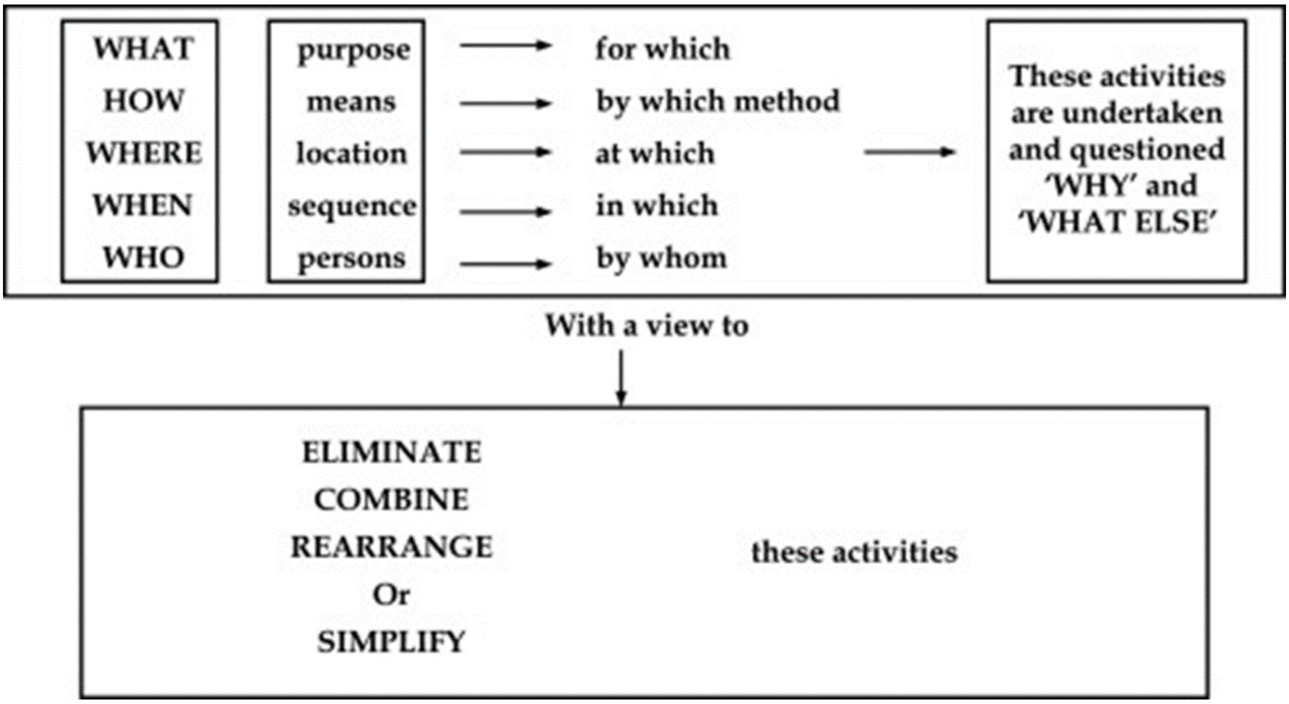


Figure 26 Primary and secondary questions (Kiran 2017)

These questions are then used to examine activities with the target of elimination, combination, rearranging or simplification. Figure 27 provides an example of the detailed questions used within this process.

DESCRIPTION OF THE OPERATION (Original/Proposed method)			Op No. Date	Chart ref. Charted by Sheet No.	
WHAT Explain the operation in one sentence	**WHY** Give reasons for doing this	**WHAT ELSE** List all possible alternatives	**COMMENT** Comment on each alternative	**WHAT SHOULD** Confirm whether the operation should be dine it not	**REMARKS**
HOW a) Specify the material b) Specify the equipment c) Explain the present method in detail d) Specify they extra safety precautions	**WHY THAT WAY** Give reasons for each	**HOW ELSE** List all possible alternatives	**COMMENT** Comment on each alternative	**HOW SHOULD** Suggest one or two procedures for each of a, b, c etc.	
WHEN a) After what operation b) Before what operation c) Frequency d) How long	**WHY THEN** Give reasons for each	**WHEN ELSE** List all possible alternatives	**COMMENT** Comment on each alternative	**WHEN SHOULD** Specify when it should be dine	
WHERE a) Exact spot b) Generallocation c) Size etc.	**WHY THERE** Give reasons for each	**WHERE ELSE** List all possible alternatives	**COMMENT** Comment on each alternative	**WHERE SHOULD** Specify where it should be dine	
WHO a) No of hands used b) Skilled/unskilled c) Men/ women d) Day/night shift e) Other details	**THY THEY** Give reasons for each	**WHO ELSE** List all possible alternatives	**COMMENT** Comment on each alternative	**WHO SHOULD** Specify who should do it	

Figure 27: An illustration of critical examination chart (Kiran 2017)

2.5.2.3 Brainstorming

The first referenced use of the phrase ‘Brainstorming’ was given by Alex Osborn (1963) in which he states, ‘it was in 1938 when I first employed organised ideation in the company I headed. The early participants dubbed our efforts ‘Brainstorm sessions’; and quite aptly so because in this case, ‘brainstorm’ means using the brain to storm a problem.’ The concept of brainstorming which further developed by Osborn and in 1957, Osborn proposed four rules: -

- idea quantity was the goal
- criticism must be ruled out
- freewheeling was welcomed
- combination and improvement are sought

Furthermore, Osborn (1963) details that brainstorming should be used to address a specific question and that sessions trying to address multiple questions were inefficient. During the brainstorming, the problem should require the generation of ideas rather than judgment; Osborn argues that generating possible names for a product, for example, as ‘proper brainstorming’. Whereas, analytical judgments, for example whether to marry do not have any need for brainstorming. In summary, brainstorming means idea generation. The definition of idea has several meanings, and these are defined in the Oxford English Dictionary. One definition defines an idea as an opinion and another definition defines idea as a notion or fancy, which equates to a guess. Moorhead and Griffin (2008) describe brainstorming as a method which ‘approves any theories, even if it is risky’ and the ‘quality of ideas will assess in the next stages and no criticism is allowed’. Fathian and Mahdavi (2008) detail how ‘a group of people are gathered in a meeting with a leader and they search for different ideas for solving a problem. The members present and describe their opinions.’ Ahmadi (2007) describe brainstorming was ‘a method that makes the members to present their opinions in a short period of time and dominates the obstacles between the units and organization’s hierarchy’.

2.5.2.4 Cause and Effect diagram

The Cause and Effect diagram, also known as the Ishikawa diagram, was a technique developed by Ishikawa for use in the problem-solving process. Ishikawa proposed that the technique was used in Quality Circles, a group meeting to discuss quality. The group would use the Ishikawa seven basic tools of quality to understand the problem. The fishbone diagram was one of the basic tools. The approach was developed as a concept in 1943 as a management problem-solving tool, yet it was during the 1950’s that the seven quality tools were used as part of the Japanese improvement activities in Kaizen events as detailed in the previous section of this chapter. The fishbone diagram is shown below in Figure 28.

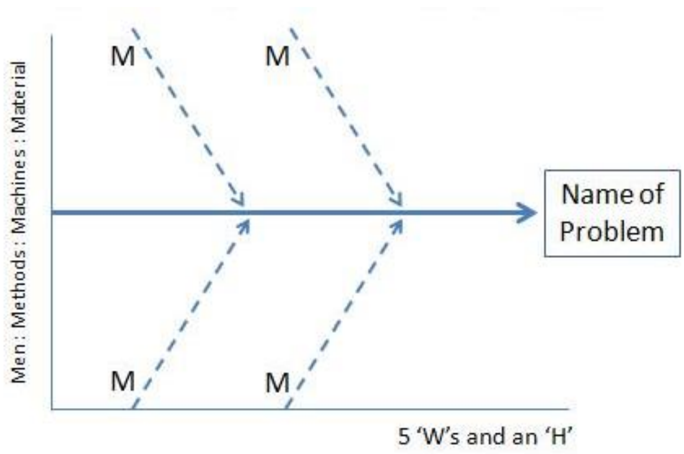


Figure 28: Fishbone diagram (Ishikawa)

A Fishbone diagram works as follows: -

The problem (or effect) is identified in the box

The four M's signify possible causes of the problem (Men, Methods, Machines, Material)

A problem-solving discussion then follows, based on the five W's and a H (Why?, When?, Where?, Who?, What? and How?).

The 5W and 1H technique is detailed later in this section of the chapter. The first cause-and-effect diagram was provided by Ishikawa from Tokyo University, when he was teaching some engineers the analysis method of different factors and their relationships with each other. The fish bone chart (or cause-and-effect) diagram shows the relationship between qualitative attributes and their related factors (Jafari & Kheradmand 2003) . Nael (2003) and Mottagi (2009) describe how the problem was shown on the main bone and the causes of the problem are indicated on the main branches, respectively. The members of the team present their approach for their elimination of the problem and the priority was given to the most important ones first.

2.5.2.5 Cause and Effect Matrix

The Cause and Effect Matrix which was developed as part of the techniques to be used in the Measurement phase of Six Sigma. The Key Performance Input Variables (KPIV's) are listed down the left side of the matrix. An importance rating was then given to each of the customer's requirements. Within the matrix, a rating of correlation from 1 (low) to 10 (high) was given for each KPIV against each customer requirement. The product of the correlation and the importance are then summed for each KPIV and ranked to obtain the most important KPIV. An example is shown in Figure 29.

Cause & Effect Matrix

#	KPIV	Grass Color (deep green preferred)	Thickness of Grass	Weeds (none preferred)													Total	% Rank
	Rating of Importance to Customer	10	8	8														
1	Fertilizer Type	10	10	10													260	19%
2	Watering Frequency	10	10	5													220	16%
3	Mower Height	10	7	7													212	15%
4	Fertilizer Frequency	7	10	7													206	15%
5	Watering Duration	10	10	3													204	15%
6	Cutting Frequency	7	7	7													182	13%
7	Operator Experience	3	3	5													94	7%
8	Brand of Mower	1	1	1													26	2%
9																	0	0%
10																	0	0%
11																	0	0%
12																	0	0%
13																	0	0%
14																	0	0%
15																	0	0%
16																	0	0%
17																	0	0%
18																	0	0%
19																	0	0%
20																	0	0%
Total		58	58	45	0	0	0	0	0	0	0	0	0	0	0	0		

Figure 29: The Cause and Effect Matrix (Lean Six Sigma Academy 2007)

No suitable academic reference which critiques the use of Cause and Effect Matrix was obtained during the literature review search. Pereira (2007) summarizes the output of the Cause and Effect Matrix as 'the key thing to remember is that this entire tool is based on opinions'.

2.5.2.6 5 Whys?

The 5 Whys is a name given to the process of asking why repeatedly until a root cause is established, it is not necessary to always ask exactly 5 whys for all problems were the technique is used. The target is to obtain a potential root cause by asking why. The technique was originally developed by Sakichi Toyoda and was used within the Toyota Motor Corporation during the evolution of its manufacturing methodologies. It is a critical component of problem-solving training, delivered as part of the induction into the Toyota Production System. The architect of the Toyota Production System, Taiichi Ohno (1988), described the 5 Whys method as 'the basis of Toyota's scientific approach . . . by repeating why five times, the nature of the problem as well as its solution becomes clear.' The tool has seen widespread use beyond Toyota, and is now used within Kaizen, Lean Manufacturing, and Six Sigma. While the 5 Whys is a powerful tool for engineers or technically savvy individuals to help get to the true causes of problems, it has been criticized by Teruyuki Minoura (2011), former managing director of global purchasing for Toyota, as being too basic a tool to analyze root causes to the depth that is needed to ensure that they are fixed. Reasons for this criticism include:

- Tendency for investigators to stop at symptoms rather than going on to lower-level root causes.
- Inability to go beyond the investigator's current knowledge - cannot find causes that they do not already know.
- Lack of support to help the investigator ask the right "why" questions.
- Results are not repeatable - different people using 5 Whys come up with different causes for the same problem.
- Tendency to isolate a single root cause, whereas each question could elicit many different root causes.

These can be significant problems when the method was applied through deduction only. On-the-spot verification of the answer to the current "why" question before proceeding to the next was recommended to avoid these issues. Rademeyer et al, (2009), highlighted four reasons why common analysis tools to define problems fall short:

1. The lack of a precise, agreed-upon definition of the required or desired performance.
2. The lack of a means of identifying what information is relevant.
3. The ability to identify the sources of relevant, needed information, or those that can best judge the degree to which the conclusion explains the variation.
4. They do not give guidance as to the remedial or corrective action that should be taken, which leads to much uncertainty and a trial-and-error adaptation of the action.

Browne and Keeley (2004) identified that the traditional 5 Whys approach was insufficient as a tool to identify root cause of problems or process. Limiting the questioning to “why” under any situation deprives the researcher from a wealth of potentially related information that can be acquired by asking more questions (2004, p. 13):

1) What are the issues and the conclusions?
2) What are the reasons?
3) Which words or phrases are ambiguous?
4) What are the value conflicts or assumptions?
5) What are the descriptive assumptions?
6) Are there any fallacies in the reasoning?
7) How good is the evidence?
8) Are there rival causes?

For this reason, traditional Root Cause Analysis (RCA) approaches such as the 5 Whys was questioned.

2.5.3 Summary of the tools and techniques

The third section of the literature review considers the tools and techniques used within the frameworks detailed in the previous section. This has been summarized in Table 6.

		Tools and Techniques						Comments
		Brainstroming	Cause & Effect diagram	Cause & Effect matrix	5 why / Asking why	5W&1H	4 Wives and 1 husband	
Frameworks	PDSA cycle	x	x		x	x		
	Kaizen	x	x		x	x	x	
	The Appreciation Process	x				x		No acedemic research
	Why because analysis (WBA)				x			Structured brainstorming
	Shainin							Copyrighted
	Military standard 1520							Linked to Global 8D
	Global 8D	x	x		x	x		
	Kepner Tregoe							Structure based on fixed method
	Six Sigma	x	x	x	x			
	A3 method	x	x		x			
	TRIZ							Structure based on fixed parameters

Table 6: Relationship between the Frameworks and the tools and techniques

(x – relationship)

The 5W&1H, 4 Wives and 1 husband and primary and secondary questions, use of why question was wide spread. Brainstorming was the approval of any theories, lack of criticism and quantity rather than quality. The cause and effect diagram was often used to capture the output of a brainstorming session. The cause and effect matrix was based entirely on opinions (Pereira, 2007). Many weaknesses of the 5 why technique have been provided by Browne & Kelley (2004), Radermeyer et al (2009) and Minoura (2011).

2.6 Trend analysis for the frameworks

This section of the literature review provides a unique count of the number of references within the academic journals to each given framework, summary in Table 7. This data was collected by using the on-line Library function provided by University of Liverpool (Discover), the setting was 'all providers' and the key work was the 'framework name' and this was filtered year by year. The list of providers runs into over 1000 databases and eJournals. The level of activities against each framework provides an indicator of the level of use for the frameworks. The development timescale of the frameworks was given earlier in the chapter.

Year	Frameworks							
	PDCA cycle	PDSA cycle	Six Sigma	Lean	Kaizen	Shainin	Kepner-Tregoe	Lean/Six Sigma
2012	86	16	433	694	177	3	4	86
2013	47	13	411	735	123	2	2	60
2014	17	70	423	702	203	2	1	96
2015	54	78	399	828	213	3	1	67
2016	52	47	324	740	167	9	3	109
2017 (YTD)	8	8	72	296	63	2	0	11

Table 7: Number of papers using the framework from 2012 to 2017(August)

The analysis of the trends from 2012 to 2017 revealed that the frameworks developed in the 20th Century are still widely used as quality problem solving frameworks. It was then assumed that the process within the framework and tools and techniques used remain little changed to the original framework.

2.7 Other recent developments within the field of research

A further search from 2012 to 2017 revealed the development of a framework for the generic process of diagnosis in quality problem solving proposed by Sanchesa, Meirelesa and da Silvab presented in 2015. The framework used 7 steps, these were detailed as follows

Step 1: Define the focus (problem) correctly. In this step, the problem should be defined correctly so that the comparison between alternatives was coherent.

Step 2: The more probable factors of the effect are defined. A list of factors should be compiled by a team (generally consisting of 3–5 people) that was fully aware of the problem and familiar with the environment in which it has occurred. To support the framework, a computer programme has been written for data entry. Within step 2, the focus (problem) and the more probable factors have been entered into the programme as a list. A Prioritisation Matrix was then created by the software. The axis of the table were the probable causes of the problem from step 2. The Matrix was then used to enable the comparison of one alternative cause with all the other causes.

Step 3: Each pair within the matrix was then assessed using the following logic.

The 'potential factor 1' contributes much less/less/the same/more/much more * than the 'potential factor 2' for the 'focus (problem)' * delete based on the teams view

A ranking score was applied to the options as follows: - much less (0.1), less (0.2), the same (1), more (5) and much more (10). This ranking was in accordance with Scarpi (2010) and Carpenter (2010).

Step 4: Compare and rate above the diagonal. In this step, a comparison was made of each line with the elements of each column, considering the contribution made to the focus point. The comparison was made considering only the values above (or to the right of) the diagonal. When the comparison was made, the text of the comparison was adopted, and the corresponding value in points. The procedure continues thus, factor by factor, initially considering the comparisons above the diagonal. To fill the spaces below (or to the left of) the diagonal, it was the transpose inverse values of the corresponding line should be given. At the end of this step, the Prioritisation Matrix has been obtained and shown in Figure 29.

	Client waits	Client complains	Lack of training	Staff do not know what	Immature Management	Unmotivated staff	Too many debts	Poor communication	Managers do not know	Irrational processes	Poor service
Client waits		10	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1
Client complains	0.1		0.1	0.2	0.1	0.1	5	0.2	0.1	0.2	0.1
Lack of training	10	10		10	0.1	0.1	5	10	1	5	10
Staff do not know what the	10	5	0.1		0.2	1	5	0.2	0.1	1	10
Immature Management	10	10	10	5		10	5	5	1	5	10
Unmotivated staff	10	10	10	1	0.1		5	1	0.1	0.2	5
Too many debts	10	0.2	0.2	0.2	0.2	0.2		1	0.1	0.2	0.2
Poor communication	5	5	0.1	5	0.2	1	1		0.2	1	0.2
Managers do not know hov	10	10	1	10	1	10	10	5		10	10
Irrational processes	5	5	0.2	1	0.2	5	5	1	0.1		5
Poor service	10	10	0.1	0.1	0.1	0.2	5	5	0.1	0.2	

Figure 29 An example of the completed prioritisation matrix (Sanchesa, Meirelesa and da Silvab 2015)

Step 5: Calculate the ratings. In this step, for each line the points obtained are added up. It should be observed that all the values are added before and after the diagonal and line by line. This was what was shown in the 'points to column' and 'points to row'.

	Client waits	Client complains	Lack of training	Staff do not know what	Immature Management	Unmotivated staff	Too many debts	Poor communication	Managers do not know	Irrational processes	Poor service	Points to Row	Normatization H 0-5	Emach
Client waits		10	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1	11.1	0.35	2.70
Client complains	0.1		0.1	0.2	0.1	0.1	5	0.2	0.1	0.2	0.1	6.2	0.00	3.69
Lack of training	10	10		10	0.1	0.1	5	10	1	5	10	61.2	3.88	-0.74
Staff do not know what the	10	5	0.1		0.2	1	5	0.2	0.1	1	10	32.6	1.86	-0.32
Immature Management	10	10	10	5		10	5	5	1	5	10	71	4.58	-1.00
Unmotivated staff	10	10	10	1	0.1		5	1	0.1	0.2	5	42.4	2.56	-0.54
Too many debts	10	0.2	0.2	0.2	0.2	0.2		1	0.1	0.2	0.2	12.5	0.44	0.95
Poor communication	5	5	0.1	5	0.2	1	1		0.2	1	0.2	18.7	0.88	-0.10
Managers do not know hov	10	10	1	10	1	10	10	5		10	10	77	5.00	-0.99
Irrational processes	5	5	0.2	1	0.2	5	5	1	0.1		5	27.5	1.50	-0.47
Poor service	10	10	0.1	0.1	0.1	0.2	5	5	0.1	0.2		30.8	1.74	0.13
Points to Column	80.	75.	21.	32.	2.3	27.	46.	28.	2.9	23	50.			
Normatization V 0-5	5.0	4.6	1.2	1.9	0.0	1.6	2.8	1.6	0.0	1.3	3.1			

Figure 30 The complete analysis (Sanchesa, Meirelesa and da Silvab 2015)

Step 6: Normalise. Each row and column were normalised using the formula:

$Ip = 5(p - min)/(max - min)$, where p is the numbers of points, min the lowest observed value of points; max the highest observed value. The normalisation follows the recommendations of Dodge (2003). This was given in Figure 30.

Step 7: Calculate the Emach of each factor. With the H and V outputs of the Prioritisation Matrix as given in Figure 31. The Emach value, named after Ernst Mach, was calculated using the following formula: $Emach_{HV} = [(V/(H + 1)) - 1]$. The Emach was defined in this because it attributes negative values to dominant factors (which contribute to the problem) and positive values to dominated factors, which make little or no contribution to the problem. The Emach expresses the meaning and power of the factor in the cause and effect (C– E) relationship. The Emach calculation enables information regarding the 'degree of causality': causal factors are negative and effect factors positive. The higher the value of the Emach, the greater the effect it has. This enables the user to determine the coherence of the analysis. The upper factors, with an Emach ≥ 0 can be considered practically spurious causal effects or factors. If a factor with little or no causal relation is included on the list of potential factors or in the analysis process, it will be discarded for lack of causal relationship and will appear at the top of the list as a spurious factor.

Within the paper on this framework the authors referred to the application of framework and detail a level of success in solving problems and when compared to brainstorming and cause and effect diagrams alone. Furthermore, the authors considered the framework an alternative to De Mast's (2013) presentation of a conceptual framework for the generic process of diagnosis in quality problems. Further claims include that for decision-making researchers, the framework can help to provide a logical structure for cause and effect and within process improvement, the framework can be useful for identifying root causes. The assessment of the

Prioritisation Matrix used within this framework reveals the matrix was like the Cause and Effect Matrix used within Six Sigma. The authors claim that the framework was an alternative can be considered true. However, the framework still has a level of subjectivity within the early steps and therefore, the potential to make the output from the later steps subjective.

To conclude the review, Big Data, has been considered. Big data are often defined by the "3 Vs" (e.g., Laney 2001) of large volumes of data generated at a high velocity from a variety of sources. Hofacker, Malthouse, and Sultan (2016) and Sivarajah et al. (2017) proposed the expansion of the list of Vs, adding veracity, variability, visualization, volatile and value. Bolon-Canedo (2015) describe the "big data" phenomenon has 'unfolding before our eyes and its transformational nature is unquestionable', and detail that '5 exabytes of data was produced every 2 days' and the 'pace of production continues to rise'. Based on these explanations, big data was not considered a framework or tools and technique, but a description for the volume of data available to the problem solver, but this would still require a framework and tools/techniques to solve any quality problem.

2.8 Research Gaps

The first research gap was the link between the definition of quality and the quality problem solving frameworks. As given by the model in Chapter 1, Figure 2. The literature review highlighted that the definition of quality broadly falls into two definitions, conformance to specification and on target with minimum variation. Garvin (1987) and Chase and Aquilano (1989) who have identified various gaps in the approaches to quality. These include the absences of a clear, conceptual framework and a 'sound instructional methodology' to help an organisation study quality and which aspects of quality matter, how much is required, and how to determine customer needs sufficiently. Although, these assessments given are based on the 1980's there was no further evidence found within the literature to fully support that these absences have been addressed. Table 7 provides the evidence that the frameworks developed post the gaps identified by Garvin and Chase & Aquilano and are still used to the current date. The framework with academic reviews reveal that the use of brainstorming was used in all cases, a technique which encourages the generation of ideas as detailed in the previous section. This creates a weakness of any techniques or tools which used the output of the brainstorming. Furthermore, this could create a degree of weakness with the effectiveness of the framework. All the experts are strong on the broad needs for quality including techniques, there was little in the way of guidance and direct benefit to the organisation from use. From the literature review, there has been little research in this area for the last twenty years, this supports a view which indicates a level of maturity in the subject matter, which was that the definition of the meaning of quality was well researched and well defined, either conformance to specification or on target with minimum variation, as presented by Montgomery (1996). Furthermore, the definitions are taken from books written by the Quality Experts, Deming, Crosby, Juran, Taguchi et al of the 20th century, so the definitions should be considered established and grounded. This research has used the definition of on target with minimum variation as a starting point for questions in the initial step of the quality problem solving framework. Defining the link, was a key component of the theory building strategy used in Chapter 4 to build the framework.

The second research gap was the research and development of a framework, which was connected to the first research gap and the weaknesses seen in the application of the tools and techniques used in the frameworks. To support this research gap, this literature review was on a parallel with that undertaken by De Mast (2013) who has examined various quality frameworks including Shainin, Six Sigma and Kepner Tregoe, De Mast proposes six strategies for diagnostic quality problem solving, these are: -

1. Lucky guess strategy – the diagnostician recognizes the symptoms of a known problem

2. Symptomatic search strategy – symptoms are used as a query in a search through a knowledge store of know problems
3. Proximate causes strategy – a more focused problem description is achieved by reasoning backward from the problem to its immediate causes. Examples included 5 whys and autopsy.
4. Branch-and-prune strategy – the search space is split into high level classes (branch); irrelevant classes are discarded from the search (prune) and the retained branches are elaborated in more detail. Examples include Bisection (half-split strategy), component swapping, multi-vari study and 4W2H.
5. Syndrome-driven pruning strategy – the search space is pruned by identifying characteristics of the causal mechanism from patterns in observed symptoms. An example is pair wise comparisons.
6. Funneling strategy – an enumerable list of specific hypotheses is tested in an efficient manner. Examples include group meeting and designed experiments.

The mapping of the various techniques/approaches against the six defined strategies and highlights that the Funnelling strategy was popular as it includes the Six Sigma approach. The Branch-and-prune strategy was used in the Shainin System approach. Following the review, De Mast concludes further research was required to try to learn about quality problem solving from empirical research, and cites this approach was occasionally undertaken in the fields of medical diagnosis and troubleshooting. Therefore, concluding that research which, 'studies of how experienced and successful problem solvers work, may enrich the theory about diagnostic problem solving' (De Mast 2013). De Mast does not propose a method or approach to enrich the theory of diagnostic problem solving. Therefore, this provided the research gap for the proposal of a framework to enrich the theory of diagnostic problem solving. Research of framework proposed after 2013 included Sanchesa, Meirelesa and da Silvab (2015) proposed framework and have cited De Mast's analysis. However, the study of the framework reveals a subjective process in which, formulated lists of probable causes within the early steps of the framework are required for the later steps in the proposed framework.

All the frameworks use tools and techniques within their processes, and these have been reviewed and analysed in this chapter. A common theme with the framework was the use of the why question. The potential weakness of the 'why' question was highlighted by Browne & Keeley (2004), Rademeyer et al (2009), Ayad (2010) and Minoura (2011). To address this weakness, the framework presented in Chapter 4 will not use the 'why' question.

Another research gap was a conceptual model to compare different quality problem solving frameworks. The literature review revealed the existence of no conceptual model. To address this research gap, a model was developed and has been presented in Chapter 4 with discussion. Further research areas considered within this thesis include the following areas: -

- The use of general solutions to quality problems and how the solutions can be linked back to the definition of quality.

2.9 Chapter Summary

This chapter includes a detailed review of definitions of quality, quality problem-solving frameworks and the tools and techniques used within the frameworks. The literature review research has concluded that there are two general approaches to defining quality. These are conformance to specification and on target with minimum variation. The definition of quality has remained unchanged since the later 20th century. The frameworks have also developed along two different routes. The more established route was started by Shewhart in the 1920's and developed by Deming in the post war development of Japan. This route was then developed by the Japanese, Ishikawa was a leader in this field. The use of Kaizen to drive improvement activities within Toyota resulted in the A3 framework. In response to the growth of Japanese companies across global markets, the second route was developed in the 1980's, led by USA based company Motorola, the Six Sigma framework. The growth of the Six Sigma framework was led by the USA based company General Electric. Other frameworks such as Global 8D developed by Ford in the 1980's was, again, in response to problems in the market place and the need to systematically solve quality problems. As most of the framework development was from the fourth quarter of the 20th century, the literature was rich in the field of quality problem-solving with many examples of both success and failure, praise and critical assessment of the techniques. Other frameworks, Shainin, Kepner-Tregoe and TRIZ have been included to complete the analysis of detailed frameworks. The detail includes the analysis of tools and techniques used in the frameworks. Having completed the analysis, it was possible to determine patterns in the tools and techniques used within the frameworks. There was also strong evidence to support the wide spread use of these frameworks in the present time. Therefore, this analysis has revealed research gaps including an opportunity to develop a conceptual model for quality frameworks to allow for comparison between frameworks, the development of a diagnostic framework for quality problem solving using the weaknesses of existing frameworks those which use the 'why' question.

CHAPTER 3

RESEARCH METHOD

3.1 Introduction

This chapter details the research method used within this research. Figure 31 provides the structure of the research and how the different research methods have been implemented through the research, shown in yellow. The purpose of providing the full detail of the research method used, it will allow other researchers to undertake and replicate this research. Having provided the method, it is important to note that are many ways to undertake research. Therefore, there was no single correct method but that the method must address the research questions. This view was supported by Easterby-Smith et al. (2002), the types and contexts of research vary so widely that the 'ideal' strategies will differ from situation to situation.

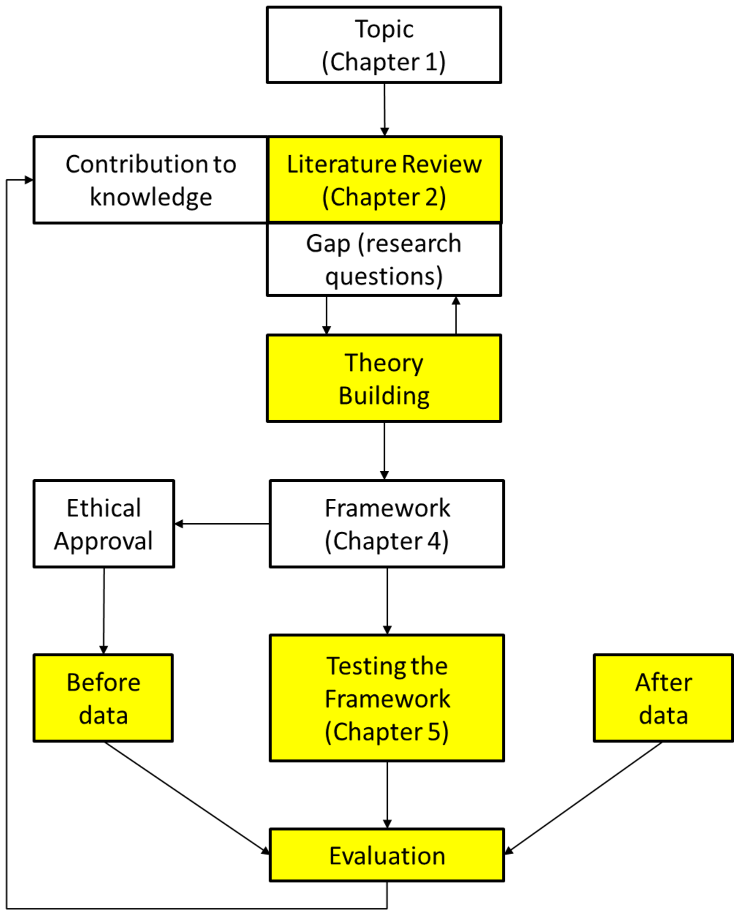


Figure 31: The structure of the research method

3.2 A review of suitable research methods

It must be acknowledged that there are many ways to undertake research and that there is no correct ‘ideal’ approach (Easterby-Smith et al (2002)). Figure 31 provides the structure used within this research. The literature review for the research method will focus on the following areas: -

- Literature Review
- Theory Building
- Testing Theories
- Primary Data Collection
- Data Analysis
- Evaluation of results

The topic of contribution to knowledge was also reviewed and has been used in Chapter 6.

3.2.1 Theory Building

A literature review of theory building research strategies revealed that, Brinberg and McGrath (1985) proposed that theory building was a conceptual domain. According to Weick (1989), too much theory building literature was mechanistic and linear, minimizing or ignoring the actual cognitive processes of thinking, creating, selecting, and judging. Doty and Glick (1994) define theory building as ‘a series of logical arguments that specifies a set of relationships among concepts, constructs, or variables’. Ragin (1994) described the role of theory building as analytical frames. Sutton and Staw (1995) concluded theory building was often mistakenly referred to as models and propositions, but the purpose of theories was to explain why, which, again, explains how. Maxwell (2005) proposed theory building as a conceptual context. Colville et al. (1999) suggest that theory building was a heuristic which allowed, for collecting and organising data. Campbell (1975), Eckstein (1975), Yin (2014) describe theories as an object of interest which can be developed, modified, and tested. The object was both the input and output of the theory. Storberg-Walker and Chermack (2006) following a review of the literature on theory building, Weick (1989), Schwartz (1991), Whetten (2002), Storberg-Walker (2007) proposed an input – process – output model for theory building, this was given in Figure 32.

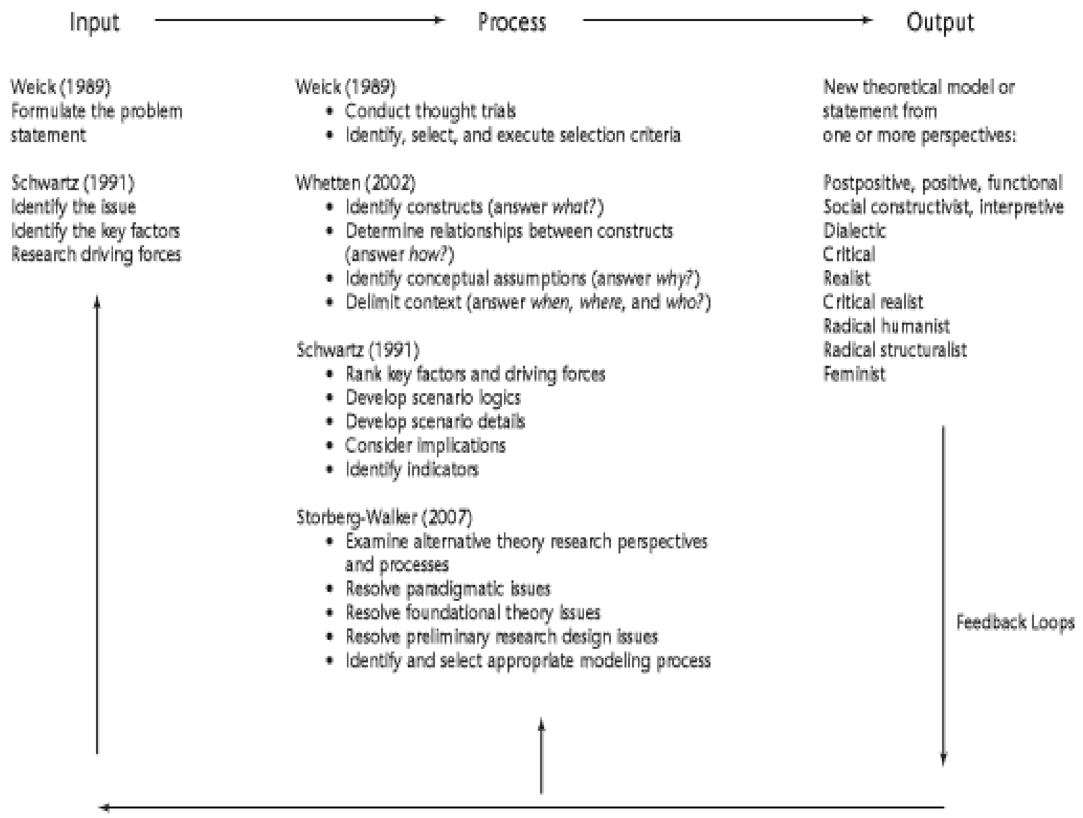


Figure 32 Model for theory development (Storberg-Walker & Chermack 2006)

Another model for theory building was given by Lynham (2002), this is shown in Figure 33. This model has a wider scope than the previous figure as it shows the complete process from theory to practice.

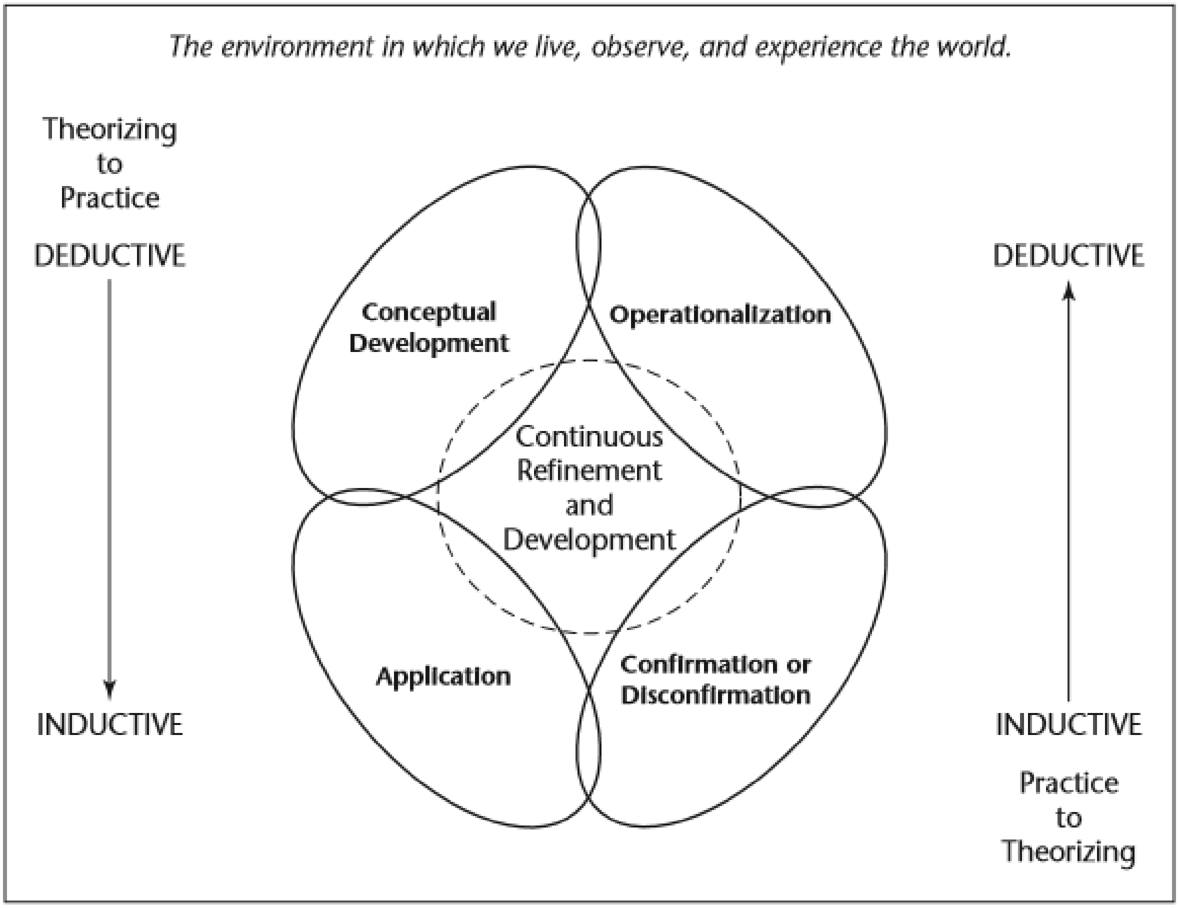


Figure 33: The Lynham framework for conceptual development

With respect to the element of conceptual development which was the theory building component, Lynham explains that this "will include the development of the key elements of the theory, an initial explanation of their interdependence, and the general limitations and conditions under which the theoretical framework can be expected to operate. The output of this phase was an explicit informed, conceptual framework which often takes the form of a model and/or metaphor that was developed from the theorists' knowledge of and experience with the phenomenon, issue or problem concerned" (Lynham, 2002, p. 15).

3.2.2 Testing Theories

Crabtree and Miller (1999) believe the aim of theory testing was ‘to test explanatory theory by evaluating it in different contexts’. This was supported by Yin (2014) who argues that theory testing was a matter of external validity. Løkke, A, & Sørensen, P (2014) propose the assessment shown in Figure 34, to highlight the difference between theory building and testing, in doing so provide a point of reference for researchers. The assessment also includes the role of case studies within each component. This was an important element of this research and used in Chapter 5 to test the theory presented in Chapter 4.

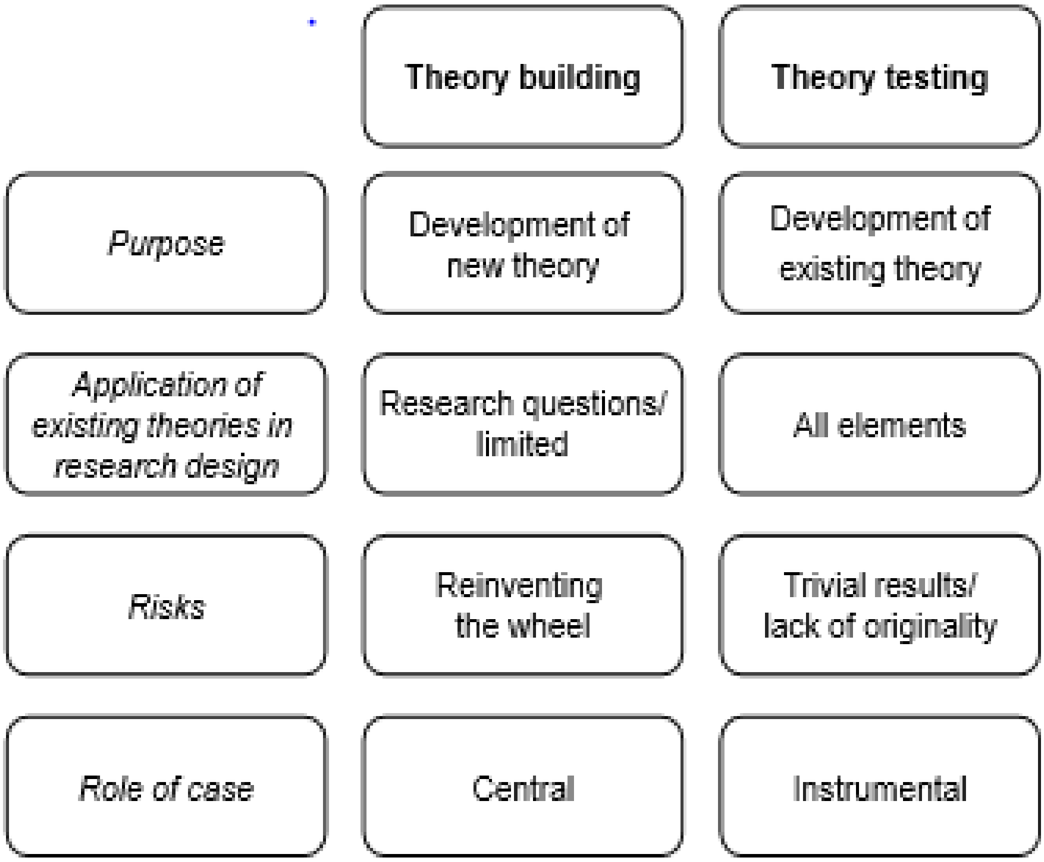


Figure 34: The difference between Theory building and testing

(Løkke, A, & Sørensen, P (2014))

Cavave (1996) highlights a potential weakness in that, when a researcher conducts a theory test, then determine logical conclusions or make predictions, because of the application of the theory, but these results are presented in faith, that the proposed theory reflects reality.

3.2.3 Primary Data Collection

Moezzi et al (2017) highlight that one of the most common definitions of story is something with a beginning, a middle, and end. This definition was useful as it allows researchers to define what stories are not. These authors also provide guidance on using stories in research, the purpose, data sources and analytical method. The purpose included data and evidence collection, understanding and fostering change, and engagement and learning. The data sources included participant observation and workshops. The analytical method included discourse analysis and written forms are the most straightforward to analyse, control, and defend as scientific evidence, though by nature they are quite different than oral forms.

A formal procedure to ensure sufficiently rigorous and defend research as reliable was the process of the action research case study, however, care is needed. The major disadvantage with action research is the neutrality of the researcher (McNiff & Whitehead, 2000). A key challenge is to ensure that the research component was sufficiently rigorous without sacrificing relevance (Argyris & Scho¨ n, 2005). These dangers cannot be eliminated entirely. In general, action research was described as a process to determine real-world solutions to real world problems. Altrichter et al. (2002) defined the action research case study as, 'an action research case study employs an action orientated approach to a prescriptive case study process combining problem solving with research in a way that is appropriate to the circumstances of the research to provide both academic rigour and practical relevance.'

A less researcher intents approach was using case studies. Yin (1994) proposed that case studies contain several data collection methods such as questionnaires, interviews, text analysis and direct observations. Furthermore, case study research, allows current theories to be enhanced with new empirical insight. Yin gives further reasons why the case study approach was preferred when a real-world event was being examined as it was a natural way to investigate the scenarios and how the project evolve. Yin’s view was supported by Stake (1995) who proposed that real-world studies are valuable for refining theory and suggesting complexities for further investigation. Yin (1994) defines three categories of case study, namely: exploratory – to find out what is happening, particularly in little-understood situations; descriptive – to portray an accurate profile of persons, events or situations, and explanatory – seeks an explanation of situation or problems, traditionally, but not necessarily in the form of causal relationships. Using Case Studies within the research allows the gap determined from the literature review to be empirically researched. Case studies constitute an important research tool in the field of management. In fact, case studies have been the source of some of the most trailblazing concepts in the field. Studies such as those by Chandler (1962), Penrose (1960), Peters and Waterman (1982), Pettigrew (1973), Prahalad and Hamel (1990), and many others, brought revolutionary insights to the field. Besides the interest in case studies as a method for generating and testing theory it has gained strength, in research in the areas of management (Cassel, Symon, Buehring, & Johnson, 2006; Eisenhardt & Graebner, 2007; Gibbert, Ruigrok & Wicki, 2008; Lee, Collier, & Cullen, 2007; Platt, 2007; Siggelkow, 2007). There was also a predominance of surveys and statistical methods – typical of positivist work and involving many cases – in the studies published by the most prestigious journals (Gibbert, Ruigrok, & Wicki, 2008; Lee, Collier, & Cullen, 2007; Platt, 2007). Yet, even if none calls in question the contribution of these landmark case studies, two facts tend to mar the acceptance of case studies in general among management researchers. One was that the most reputable journals of management publish few articles based on casework. The other fact was that this research method was often criticized in terms of its inherent inability to meet standard scientific criteria for research. Such criticism comes primarily from scholars with a positivist, normal science orientation. For some of these researchers, case studies may be used in research but are considered appropriate only in the preliminary stages of developing a new theory, when the relevant variables are still being explored (Cassel, Symon, Buehring, & Johnson, 2006; Eisenhardt, 1989; Lee, Collier, & Cullen, 2007; Platt, 2007). Such criticism may explain the relative scarcity of published cases in reputable journals, but other reasons – such as the usually large and long effort needed to conduct a case study (Yin, 2009) – may also be contributing factors. The contributions from theory testing case studies can be diverse 'to strengthen or reduce support for a theory, narrow or extend the scope conditions of a theory, or determine which of two or more theories best explains a case, type, or general phenomenon' (George and Bennett 2005: 109).

A component of case study research as given by Yin was the use of questionnaires. Eta (2008) defined a questionnaire as a set of questions for gathering information from individuals. You can administer questionnaires by mail, telephone, using face-to-face interviews, as handouts, or electronically (i.e., by e-mail or through Web-based questionnaires). Questionnaires can be used for data collection and are designed to collect data in a structured manner. The whole sample was given a collection of questions which are the same for the whole sample. The Likert scale was widely used for the responses, in this situation the questions are closed, therefore with limited response options, and this scale was used for the analysis of the questionnaires. Clearly, if open questions are used they allow the capture greater detail. Questionnaires can be used as part of a structured interview and used face to face with the sample respondents. Questionnaires are most commonly used over the phone, or sent via email or post. If questionnaires are posted it is important to include a stamped, addressed envelope, but this does not guarantee a response. The questionnaire must be structured and laid out, to lead the respondent through the questionnaire with minimal confusion. Response rate is vital with any questionnaire to ensure valid and reliable data; failure to achieve a meaningful sample was likely to lead to bias and invalid conclusions from the analysis. Taylor-Powell (1998) provide a full assessment of questionnaires including definitions, best practice and pitfalls.

Matthews and Ross (2010) define the interview as a data collection method which often: -

- Facilitates direct communication between two people, either face to face or at a distance via telephone or internet;
- Enables the interviewer to elicit information, feelings and opinions from the interviewee using questions and interactive dialogue

Face-to-Face interviews bring the expressive power of language to provide a most important resource, a critical feature of language is the ability to describe, explain and evaluate about any aspect of the world according to Hammersley and Atkinson (1995). Interviews, Breakwell (1995), are extremely flexible and are split into three types, structured, semi-structured and unstructured. A further dimension was added by sharing experiences or storytelling to gain greater insight from the respondent. The best way to capture data from an interview was to record the interview and then use a step by step play back to capture the data or expressions if video was used. Brewerton and Millard (2001) describe the importance of allowing an interview to unfold at the respondent's pace to fully capture the true feelings about the area of research. Brewerton and Millard (2001) describe the disadvantages of interviews as cost, time-consuming, accessibility, open to bias and poor reliability.

Triangulation must be considered in any research, that was, the research method 'must view' the research questions from different angles and points of view. McCutcheon and Meredith (1993) believe that "with case research, thorough analysis and data triangulation (use of multiple sources and methods) can help to get the most accurate picture of events".

3.2.4 Evaluation of results

When undertaking research, the importance of demonstrating the trustworthiness of the research outcome provides validity for the support. Guba's (1981) model of trustworthiness was considered well developed; it has four components: truth value; applicability; consistency and neutrality. The aspects of Guba's model are: -

Truth value – Lincoln &Guba (1985) state that truth value asks whether the researcher has established confidence in the truth in which the study was undertaken.

Applicability – refers to the degree to which the findings can be applied to other contexts and settings or with other groups it is the ability to generalize from the findings to larger populations. In the quantitative perspective, applicability refers to how well the threats to external validity have been managed. (Sandelowski, 1986).

Consistency – whether the findings would be consistent if the enquiry were replicated with the same subjects or in a similar context. (Krefting, 1990)

Neutrality – the freedom from bias in the research procedures and results. (Sandelowski, 1986).

A further point to consider was the aspects of sample size and statistical power tests. Miles and Huberman (1994) proposed a series of tests to apply to case study research:

- Is it relevant to the conceptual frame and research questions?
- Will the phenomena to be studied appear? Can they appear?
- Is it one that enhances generalisability?
- Is it feasible?
- Is it ethical in terms of informed consent, potential benefits and risks and relationships with informants?

Voss et al (2002) concluded there was a temptation to do `just one more case' or `just one more interview' to test the research theory. However, the most important issue as to when to stop was when you have enough cases and data to satisfactorily address the research questions. This view, supports Cavave (1996) detailed earlier in this chapter in which the reality matches the data collected during research. An important development to aid the analysis of data was the concept of hypothesis testing. Hypothesis testing was developed in the early 20th century by

Neyman and Pearson. Figure 35 shows the concept of hypothesis testing; the vertical axis measures the 'truth' that is either the null hypothesis or the alternative hypothesis is true, and the horizontal axis measures the 'data decision' which is to either to select the null hypothesis or the alternative hypothesis. The convention with the 'data decision' is to test under the null hypothesis conditions and either accept or reject the null hypothesis using a preselected cut off point. This will be discussed in Chapter 5 following the case studies.

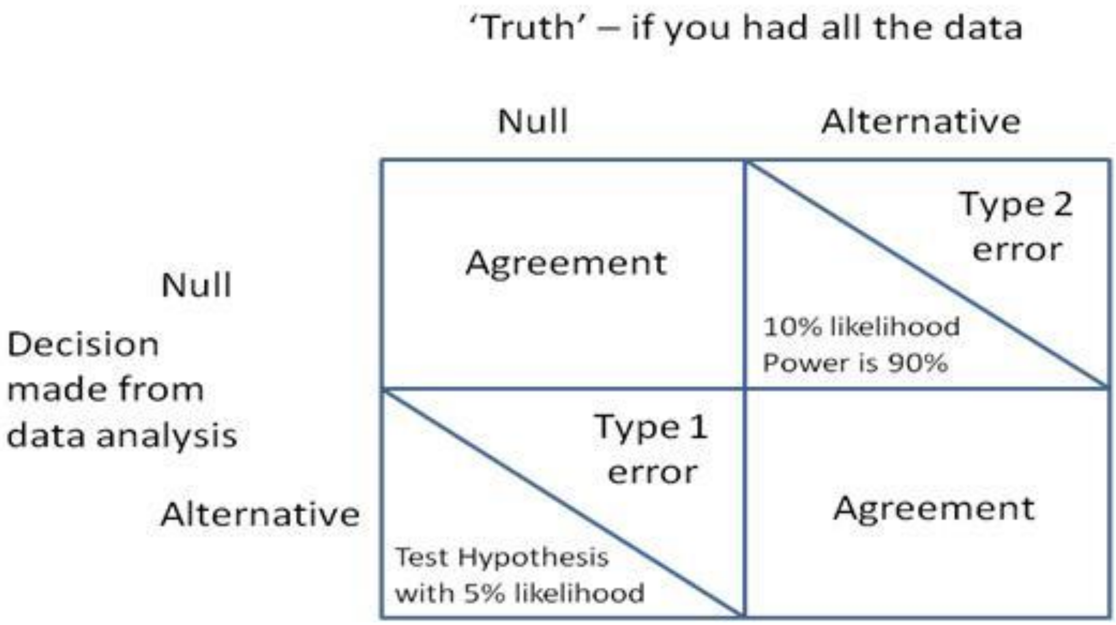


Figure 35: The concept of hypothesis testing, power and sample size

Prior to the use of the technique in Chapter 5. Hypothesis testing in a context of case studies testing a theory would compare the pre-and post-data the application of the theory. Therefore, the hypothesis for testing would be presented as follows: -

Null hypothesis: Problems pre-use of the theory = Problems post use of the process

Alternative hypothesis: Problems pre-use of the theory ≠ Problems post use of the theory

If the outcome of the hypothesis test supports the rejection of the Null hypothesis, then this supports the positive outcome of using the research. This analysis should be undertaken a suitable and valid statistical package. A further point to considered was the power of the statistical test, that was described by Cramer (1946), van der Waerden (1957) and Lehmann (1959) as the probability that the statistical test correctly rejects the null hypothesis when the null hypothesis was false. It can be equivalently thought of as the probability of correctly accepting the alternative hypothesis when the alternative hypothesis was true. This is the ability of a test to detect an effect, if the effect exists. The power is a function of the possible distributions, often determined by a parameter, under the alternative hypothesis. That is, as the power increases, the chances of a Type 2 error occurring decreases. The probability of a Type 2 error occurring is referred to as the false negative rate (β) and the power is equal to $1-\beta$. The power is also known as the sensitivity. Power analysis can be used to calculate the minimum sample size required so that one can be reasonably likely to detect an effect of a given size. Power analysis can also be used to calculate the minimum effect size that was likely to be detected in a study using a given sample size. The use of power and sample size within research appears to be an uncommon practice. A view supported by Mason's (2010) who reviewed, sample sizes in qualitative research and explored the concept of saturation, that was, how much data was required to support the research hypothesis. The research concluded that sample sizes tended to end with a zero, therefore 10, 20, 30, 40, and so on interviews were conducted. This result was counter to the use of power and sample size which rarely ends with a zero. There has been research undertaken by Maxwell et al (2008) in the field of Psychology which supports the research of Mason. Maxwell et al (2008) state that a 'study must be of adequate size, relative to the goals of the study. It must be "big enough" that an effect of such magnitude as to be of scientific significance will also be statistically significant. In an experiment involving human or animal subjects, sample size was a pivotal issue for ethical reasons. An undersized experiment exposes the subjects to potentially harmful treatments without advancing knowledge. In an oversized experiment, an unnecessary number of subjects are exposed to a potentially harmful treatment or are denied a potentially beneficial one. For such an important issue, there was a surprisingly small amount of published literature.

Graphical techniques are an effective method for representing the outcomes of research. The technique of Statistical Process Control developed in the 1930's by Shewhart is recognised as an analytical method to determine a change in process behaviour. 'Statistical Process Control (SPC) is an industry-standard methodology for measuring and controlling quality during the manufacturing process. Quality data in the form of Product or Process measurements are obtained in real-time during manufacturing. This data is then plotted on a graph with pre-determined control limits. Control limits are determined by the capability of the process, whereas specification limits are determined by the client's needs. Data that falls within the control limits indicates that everything is operating as expected. Any variation within the control limits is likely due to a common cause—the natural variation that is expected as part of the process. If data falls outside of the control limits, this indicates that an assignable cause is likely the source of the product variation, and something within the process should be changed to fix the issue before defects occur'. (http://www.infinityqs.com/resources/what-is-spc)

Another graphic representation was the use of the cumulative average plotted against the actual data, if the pattern in the cumulative average has a level trend then the data collected can be considered representative of the process which was under examination.

Another suitable metric to evaluate pre-and post was, Defects Per Million Opportunities (DPMO). This metric is used within the Six Sigma Framework, described in the previous chapter. The metric is calculated as follows:

$$DPMO = (\text{Number of defects}) \times 1000000 / (\text{Number of opportunities})$$

Another metric to considered was cost saving and this was measured both before and after implementation of the research topic. Within this research the cost saving is based on the accounting method used by the companies in the case studies.

3.3 Detail of the Research Method within this research

The high-level structure of the research method was presented in Figure 25. This section of the chapter provides the detail of the research method. The topic for research was described in Chapter 1, in which potential research opportunities are introduced. Chapter 2, the literature review, follows the guidance of Mays et al (2001) and Whittlemore and Knafl (2005) in which the major sources of data were appropriate internet sites. The output of this review was presented in Chapter 2. In the latter part of Chapter 2, the research gaps are revealed and presented as a series of research aims and research question detailed in Chapter 1. Following a literature review of different approaches to describe the research approach, the researcher has concluded that the research was initially theory building and, cites the explanations of theory build given by Doty and Glick (1994), Ragin (1994). Elements of the input-process-output framework given by Storberg-Walker & Chermack (2006) have been used as evidence to support this view. Within this research, the review of De Mast detailed in Chapter 2 provides the justification for the theory building. De Mast concludes that 'studies of how experienced and successful problem solvers work, may enrich the theory about diagnostic problem solving' (De Mast 2013). As already stated, De Mast does not propose a method or approach to enrich the theory of diagnostic problem solving. Therefore, this provided the research gap for the proposal of a framework to enrich the theory of diagnostic problem solving, this process is given in Chapter 4. Finally, Lynham (2002) proposed a framework with a wider scope and this has also been used in this research to justify and test the theory given in Chapter 4. Prior to testing the theory, ethical approval was obtained for the primary research, the detail of this is presented in Appendix 1. This appendix also includes the primary data questionnaire used. Further to the use of the questionnaire, there was other criteria to guide the selection of the case studies, these were as follows: -

1. The author has worked with the companies.

2. The author has trained the users within the company in multiple problem-solving methods including the framework in Chapter 4.
3. There was a measurable quality problem within the company (before and after data available)
4. The users have agreed that the case study can be used as part of the research.

Following the training the user was left to solve the problem and the results of following the framework given in Chapter 4 was presented in the format of a case study using the questionnaire to structure the results. Although, the researcher was available to guide the use of the framework, researcher was not directly involved in solving the problem. Based on this, the research cannot be considered action research using the definition as given earlier in the chapter. Having obtained ethical approval, the testing of the framework was undertaken. In summary, the theory for testing was that the existing problem-solving frameworks display shortcomings, given in Chapter 2. Chapter 4 provides a theory (the research question) to address the weakness, and Chapter 5 provides a demonstration of the theory using both stories, weak research, and case studies, rigour research.

Løkke, A, & Sørensen, P (2014) describe the difference between building and testing theory and the role of case studies in each context. Cavave (1996) highlights a potential weakness of faith in the results obtained from a theory and believing the results reflect reality. To address this potential weakness, appropriate evaluation techniques have been used in this research, to the point where it was possible to demonstrate a contribution to knowledge to the required academic level. Using the Løkke, & Sørensen, (2014) research, the use of case studies presented in Chapter 5 can be viewed as both central to demonstrate the framework and instrumental in testing the effective of the framework to solve quality problems. The use of difference primary data collection methods has been presented in this chapter. The justification of using case studies was, mainly driven by Yin (1994). He describes case studies as a mixture of several data collection methods, allow current theories to be enhanced with new empirical insight and allow gaps in literature reviews to be empirically researched. These three elements describe the research in Chapter 5. Also, within Chapter 5 was the presentation of the evaluation of the further stories and case studies. The scope of the ethical approval has resulting in these quality problems being presented as stories rather than full case studies in the same detail as those given in Chapter 5. To assess the results of the research the following methods have been used: -

- The metric – DPMO (Six Sigma)
- The use of SPC (1931)
- Hypothesis Testing (1920's)
- Cumulative average plot
- Cost Saving

These metrics have a degree of longevity and are therefore, considered valid metrics for this research.

In this research the hypothesis test used was the 2 proportions test, known as the 2 P test. The rationale was driven by the before and after aspects of using the 4-Stage framework, this test allows for data collected before and after to be statistical tested as a binary attribute, that was, improvement or no improvement.

The formula for the 2 P test is given as (taken from Minitab): -

$$Z = \frac{\hat{p}_1 - \hat{p}_2}{\sqrt{\hat{p}_o(1-\hat{p}_o)\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}}$$

where

$$\hat{p}_o = \frac{x_1 + x_2}{n_1 + n_2}$$

The p-values for each alternative hypotheses are given by:

$H_1: p_1 > p_2$: p-value = $P(Z_1 \geq z)$

$H_1: p_1 < p_2$: p-value = $P(Z_1 \leq z)$

$H_1: p_1 \neq p_2$: p-value = $2P(Z_1 \geq |z|)$

Calculate these probabilities on the standard normal distribution

Notation

p_1 = the true proportion of events in the first population

p_2 = the true proportion of events in the second population

$\hat{p}_1$ = the observed proportion of events in the first sample

$\hat{p}_2$ = the observed proportion of events in the second sample

$\hat{p}_o$ = the pooled estimate of p (pooled observed probability)

d_0 = the hypothesized difference between the first and second proportions

x_1 = the number of events in the first sample

x_2 = the number of events in the second sample

n_1 = the number of trials in the first sample

n_2 = the number of trials in the second sample

The P-value cut off for the rejection of the Null Hypothesis is a P value less than 0.05. Therefore, a value equal or greater to 0.05 would accept the Null Hypothesis.

The final point of contribution to knowledge was the framework given in Chapter 4 and how the contribution builds on existing knowledge as given in Table 10, Chapter 4. The case studies and stories demonstrate the framework has practical application. The conceptual model for testing quality problem solving frameworks was presented as no other model was discovered during the research.

3.4 Chapter Summary

This chapter provides the detail of the research method which has been used in this thesis. A full review of research methods has been undertaken and those considered suitable have been detailed in the literature review in this chapter. By studying existing research methods, it allows this research method to be conceived. The method needs to be described in detail, so it can be followed step by step, not only by the author but other researchers. The aim of the research method is to ensure similar conclusions would be drawn independent of the researcher. This research which was proposing a conceptual model/framework/detailed process for quality problem-solving, the initial problem statement has highlighted possible research opportunities. The literature, secondary data, books and journals have been assessed and analysed to determine if evidence exists to support the research questions. A further area to support the literature review is examples of problems already solved using a fact-based approach. These examples have been assessed comparing the data before and after the quality problem-solving activities. By using the findings from the literature review, a quality problem-solving framework was proposed. This chapter details the method to test the process developed in Chapter 4 via the use of case studies. To test the case studies, a series of metrics are used with the pre-and post-framework data. The techniques include, using the SPC technique (pattern), the cumulative average plot (sample size), DPMO (change in defect rates) and a suitable hypothesis test (P value less than 0.05). The criterion for successful application of the framework (Chapter 4) was given for each metric. This thesis will test the framework given in Chapter 4 and the reliability of the framework was discussed. However, measuring the reliability was for future research.

CHAPTER 4

DEVELOPMENT OF A QUALITY PROBLEM-SOLVING FRAMEWORK

4.1 Introduction

Chapter 2, section 2.8 detailed the research gaps. This chapter provides the history of analysis undertaken to demonstrate how the gaps have been researched and addressed. Prior to the development of a new framework of quality problem solving, the current frameworks and tools and techniques are, again, analysed in greater detail. This analysis begins in section 2.5.3 of the literature review. Also, included within this chapter was the development of a Conceptual Model to compare quality problem solving frameworks. This will address the third research aim, but the discussion on this third question continues in Chapter 5.

4.2 Addressing the weaknesses from the literature review

This section of the chapter returns to the findings of the literature review and provides further discussion on the research gaps.

Many definitions of quality were presented in the literature review: Juran (1974) Crosby (1979) Drucker (1985) Deming (1986) Six Sigma (1988) Taguchi (1992) Chowdhury (2005) Elias (2015) ISO standard (2017) and the two main definitions of quality presented were: -

- conformance to specification (Deming plus others)
- on target with minimum variation (Taguchi)

This research evidence suggests a lack of evidence to link the definition of quality to a quality problem solving framework and proposed a representative of the thinking to demonstrate the shortcoming in Figure 2. However, the lack of evidence may be a research weakness. However, no suitable research evidence was found. Under the assumption of this potential weakness the following was presented. The use of the definition, ‘on target with minimum variation’ within the quality problem solving framework was presented within this chapter. The rationale for using this definition was to ensure quality has a single meaning linked to the target and that any variation from the target can be described as a quality problem. In a situation where no target was present the outcome was only variation was possible. This point will be discussed within this chapter.

The tools and techniques were common to many of the frameworks as shown in the literature review (Table 6). Further analysis concluded that the existing frameworks and the tools and techniques, developed in the 20th century, are still in wide spread use in the 21st century (Table 7). There has been little development in new frameworks to solve quality problems, and no new tools and techniques. Despite, Sanchesa, Meirelesa and da Silvab (2015) claiming that their framework for problem solving offers a 'new' approach, the tools used were subjective within the analysis phase. To clarify, it was subjective, because a predetermined list of possible root causes are required prior to the problem occurring and a ranking system was used to determine the most likely root cause. The authors of the framework state the research of De Mast (2013). The research into frameworks undertaken by De Mast (2013) detailed in the literature review provides a comprehensive review of the state of quality problem solving frameworks, which further supports the data presented in Table 7. Therefore, any new framework should address the gap detailed by De Mast (2013). The main outcome was the enrichment of the theory about diagnostic problem solving achieved by the study of how experienced and successful problem solvers work.

Defining the main framework steps was a clear process. In brief, it must provide a clear definition of quality and therefore, a clear definition of a quality problem, and detailed process steps from the problem to the solution, with no subjectivity. The complexity of the framework lies in the application of the tools and techniques used within the framework process steps. Therefore, by re-examining the weaknesses of the tools and techniques discussed in the literature review, the detailed structure of the framework was developed. Tools and techniques which have the potential to provide a subjective outcome from their use pose a weakness when problem solving. This was not considered by the framework given by Sanchesa, Meirelesa and da Silvab (2015) for the reasons given earlier in this section of the chapter. A major source of generating subjective outcomes seen within the literature review was the use of asking the ‘why’ question during the application of the problem-solving framework. However, this was not just confined to ask why, other tools and techniques used in problem solving result in subjective outcomes, including brainstorming and using fishbone diagrams to capture possible root causes. A view supported by Shainin (1993) who highlighted, ‘there was no place for subjective methods such as brainstorming or fish bone diagrams in serious problem solving.’ The Shainin view appears to have gained little traction within main stream problem solving, based on the evidence in the literature review (Table 6 and Table 7). That was, these three tools and techniques are key components of the commonly used frameworks for quality problem solving.

The analysis in this chapter has used three criteria to assess the tools/technique detailed in the literature review: -

- Facts – Following the use of the tool/technique the outcome was a fact as proven with data
- Opinions – Following the use of the tool/technique the outcome was an opinion and further data was required to prove validity
- Guesses – Following the use of the tool/technique the outcome was a guess and further data, if deemed necessary, would be required to validate the guess

The criteria descriptions have been used to analyse whether the output of using the tool or technique results in an outcome which is either facts, opinions and guesses. In doing so, the impact on the outcome of using the framework has been assessed. The tools and techniques: Brainstorming, Ishikawa diagram, 5 whys and 5W & 1H (using why and including 4 ‘wives’ and 1 ‘husband’) are considered following the literature review. Graphical techniques have not been considered for the reason given in the literature review, that was, data was required to use a graphical technique.

The assessment begins with Osborn (1957) who believed brainstorming was about generating quantity of ideas which equalled quality of ideas. Therefore, logic dictates facts, opinions and guesses will be part of the brainstorming. A further finding of this research was that there was no reference to 'Osborn' brainstorming linkage to quality improvement techniques. The authors' research has failed to find a link between Osborn and Ishikawa. That is, the Osborn process of marketing brainstorming to generate a large quantity of ideas was referenced by Ishikawa as the method he used to develop the cause and effect diagram which was populated using the brainstorming technique. This was interesting and could explain why brainstorming was still used, as the timeline of the frameworks PDSA (Plan, Do, Study, Act) with brainstorming used in the 1960's developed into Six Sigma in the 1980's. There was research evidence, Chapter 2, to suggest this was the case, JUSE (Japanese Union of Scientists and Engineers) involvement with Florida Power & Light and the discussion of Six Sigma. This is a potential area for further research, considered in Chapter 6.

The brainstorming process involves asking the question, what was the cause of problem XYZ? Any brainstorming group, following Osborn's rule, facts, opinions and guesses will be generated. In general, brainstorming is about allowing participants to express their views, as discussed in the literature review. Moorhead and Griffin (2008) Fathian and Mahdavi (2008) Ahmadi (2007)

To collect the potential causes of a problem the Ishikawa fishbone/Cause and Effect diagram was used. This technique used as part of the PDSA cycle, PDCA cycle, Kaizen, the Pentagon 5 step process, Six Sigma, Global 8D and the A3 process. The application was therefore widespread within quality problem solving. Therefore, the link between brainstorming, facts, options, guesses can be directly linked to the Ishikawa fishbone/Cause and effect diagram. The fishbone only provides a structure and little else.

Evidence for the use of the 5W and 1H method was available, it appears to be split into two areas, that of journalistic questioning (2007, 2008) and the other was business improvement (2010). In all researched cases, the method uses the 'why' question as an element of the statement. In some cases, the 'why' formed a single question often with what, who, when and where but in others, it was used as a single question asked 5 times, why – why – why – why – why leading to the 'how' question. Therefore, as the 'why' question was used and under the assumptions of this research would allow for facts, opinions and guesses as part of the problem-solving framework.

With respect to the frameworks not already considered, the analysis reveals the following: there was no evidence that the Appreciation Process has had any academic research undertaken to determine the benefits, issues or applications. The Shainin system (1993) which was copyrighted and therefore difficult to critique as detailed in the literature review will not be considered further. To clarify the detail of the other frameworks; Global 8D (2012), also has several approaches under the same name. Research into the Global 8D method indicates that the method was a practical tool developed within business, with practical benefits but with little research into the benefits. In the context of this research, the process uses brainstorming and 5 whys, but it does encourage the use of facts in the problem definition process.

The review of the use of the Six Sigma DMAIC (1988) process reveals a wide use in large, global businesses Lucier and Seshadri (2001) Snee and Hoerl (2004) Bovarnick (2006) Pulakanam (2012). There was evidence of major cost savings with the application of Six Sigma. The literature review of the DMAIC process reveals a structure/process to follow, but within each process step, individual tools are used (2001). For example, using brainstorming to generate ideas as to the root cause of the problem. Other techniques are used to structure the brainstorming outcome, for example the Cause & Effect matrix to rank the facts, guesses and opinions collected from the brainstorming session. The matrix has been described as totally 'based on opinion'. (Pereira, 2007). This point was further supported by a review of the Six Sigma ISO standard (2015) which provides detail on the use of brainstorming, Cause & Effect diagram and Cause & Effect matrix.

The review of A3, which originates in Toyota, and has strong links to Kaizen as detailed in the literature review (2006). The use of the method was heavily linked to the culture of Toyota. As with other Toyota business philosophies, the meaning and application of the technique 'gets lost', (Macpherson et al, 2015), as the Toyota 'method' was applied in other business sectors. During this review, several different approaches to the A3 have been found (2008) (2011). The overall structure was the same, yet the tools used differ. The use of brainstorming, cause and effect diagrams and 5 whys will ensure opinions and guesses are part of the A3. In another approach of the A3, the need to have a baseline standard was vital prior to the start of the framework. However, the lack of a standard maybe the root cause of the problem. This supports the concept of using 'on target with minimum variation' as a definition of quality to link to the framework. In doing so, the issue with the A3 framework in which the perspective of the problem can be subjective, that is, different views on the same problem, was removed.

Following this analysis, the frameworks and the tools and techniques can be mapped, this was a continuation of Table 7 from the literature review. Using the categories; facts, opinions and guesses to assess the tools and techniques the results shown in Table 8 are concluded.

Tools/Techniques \ Frameworks	Ishikawa - Fishbone	5 Whys	Cause & Effect Matrix	5W + 1H (Why)	Brainstorming
PDCA/PDSA/Kaizen	x	x		x	x
A3 method	x	x			x
Global 8D	x	x		x	x
Six Sigma	x	x	x		x
5 step pentagon	x	x			x
Why Because Analysis					x
Appreciation process		x		x	x
TRIZ					

Tools Techniques \ FOG	Ishikawa - Fishbone	Cause & Effect Matrix	5 Whys	5W + 1H (Why)	Brainstorming
Facts	x	x	x	x	x
Opinions	x	x	x	x	x
Guesses	x	x	x	x	x

Table 8: The relationships between Frameworks, tools/techniques and Facts Opinions Guesses (FOG) (x – relationship)

To further support this analysis, Reid and Smyth-Renshaw (2012) highlight the following observation that a typical Western approach to Root Cause Analysis would involve a brainstorming approach to determine the likely sources of the problem. This analysis does not include the Shainin approach (1993) for reasons given earlier in Chapter 2 and the Military Standard 1520C. The Military Standard 1520C which has no academic reference, is a standard but does not provide a process and has been included for completeness as it provides the standard from which the TOPS and later the Global 8D process were developed. The next section of the chapter provides the history of the development of the quality problem solving framework to address the research gaps highlighted within the literature review and discussed further in this section of the chapter.

4.3 The history of research undertaken to support the development of the framework

This section of the chapter provides the history of the research undertaken to support the development of the framework detailed later in the chapter. The initial concept has 2 stages which involves: -

1. 5W&1H procedure

2. How does it work? (This includes WWBLA (Why Why Because Logical Analysis)).

The purpose of this research was to develop an effective implementation model, whether standards exist or not, which consists of 5W+1H without asking the question 'why'. This was performed using a framework based on the fishbone diagram presented by Ishikawa in Figure 36. As with the A3 approach, the aim was to clearly define the problem. In situations where '5W+1H' model has several gaps and further data was required, the 'why why because logical analysis' (WWBLA) structure was used, discussed in detail in Step 2. The '5W&1H fishbone diagram' helps to visualise and convey the important relationships between the 5W+1H elements. In summary, by knowing and controlling 'why', variability in root cause was reduced, in short, focusing on facts and not guesses in determining the root cause.

4.3.1 Stage 1

Stage 1, the 5W&1H procedure was presented as follows: -

What – what product/service? The description of the product or service that has experienced the problem, if serval products are using a common process and only one problem has the problem, this could indicate the design of the product as a potential root cause. It was unlikely that for a service problem, this question would yield any information other than the name of the process.

Who? – This question was aimed at determining the people who are present at the time of the problem.

When? – This question was concerning the timing of the problem; further, it was possible to examine possible trends in the problem occurrence. If a problem has a trend, for example, the problem occurs every Monday at 11am, this was very important in the problem-solving process.

Where in the process? This question was concerned with the step in the process 'where' the problem was seen. It is important to understand where in the product/service life cycle or process the problem has occurred, which is likely to involve mapping the process to answer this question.

Where on the product? This was the position on the product ‘where’ the problem was seen. If the problem was only seen in one position, then the root cause was likely to be easier to determine than a product with multiple problems seen in various positions across the product.

How is the deviation from target? The product or service should have a standard target condition which is the ideal condition. This target could be known as perfect quality. The aim of this question is to describe the deviation from this target.

The aim was to have a clear problem statement using the 5W+1H statements and a fishbone as shown in Figure 36. The deviation from target (how) was seen (when) by (who) on product/service (what) in position (where) and in the location (where). In the case of a problem where the knowledge has gaps, it was often helpful to ask, ‘how does it work?’.

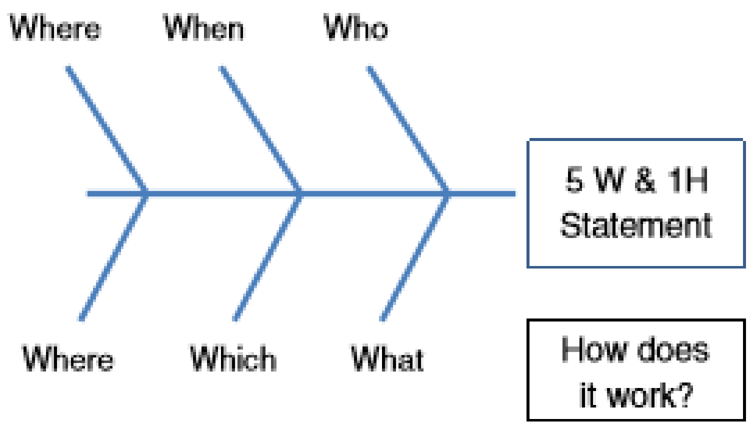


Figure 36: RCA – 5W + 1H fishbone

4.3.2 How does it work?

Having used the 5W+1H as detailed in the previous section, defining the problem may require a deeper analysis. This is often the cases in either a complex service or a product, which was often useful to try to describe how a product or service should work or operate. Therefore, for a product, this would involve a breakdown of any assemblies into parts to examine the function and fit of the parts. For a service, the situation is different, and the use of process mapping would be required to understand the service function. This structure of questions and fishbone structure can be used not with the traditional 4M headings (man, machine, material and method), but using the 5W+1H headings. This approach expands the fishbone structure as the heading of 'man' was who in the 5W&1H and headings 'machine', 'material' and 'method' are all where within the 5W&1H. The target of using the fishbone structure was to have one actual root cause. If necessary, the five why method can be used to get to a root cause which can be actioned to remove the root cause. This is shown in Figure 37.

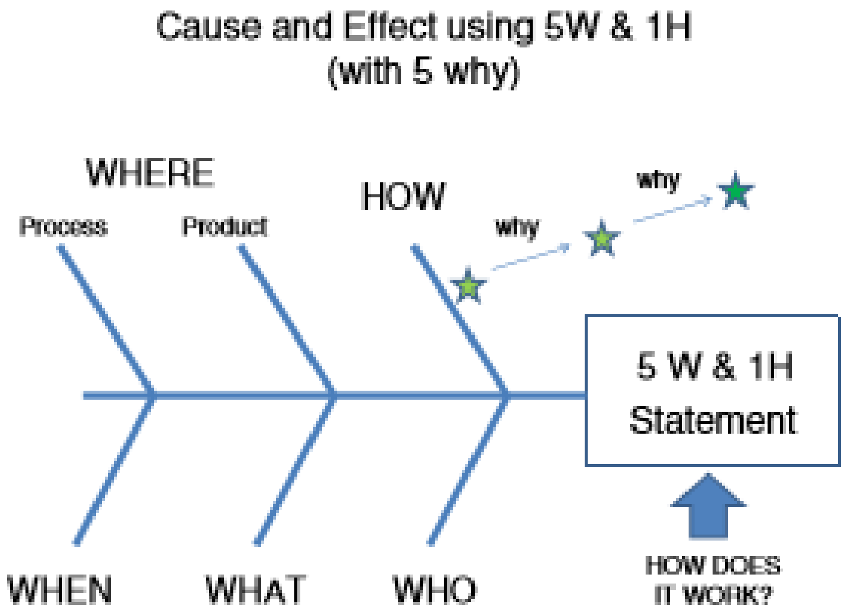


Figure 37: The initial framework

Asking 'why' was sensible as the root cause chain has been determined and asking why only brings further clarification and understanding to the problem. Therefore, this minimises the likelihood of problem reoccurrences. The structure can be used to highlight the missing data against each W. This approach introduces a further step using a technique called Why Why Because Logical Analysis (WWBLA). Having not asked why, the understanding of the problem was all fact based but the root cause was not determined, so the WWBLA technique allows logical causes to be listed and the why technique to be used to obtain an action of data collection to verify whether the logical cause is a ‘true’ root cause. This structure is shown in Figure 38.

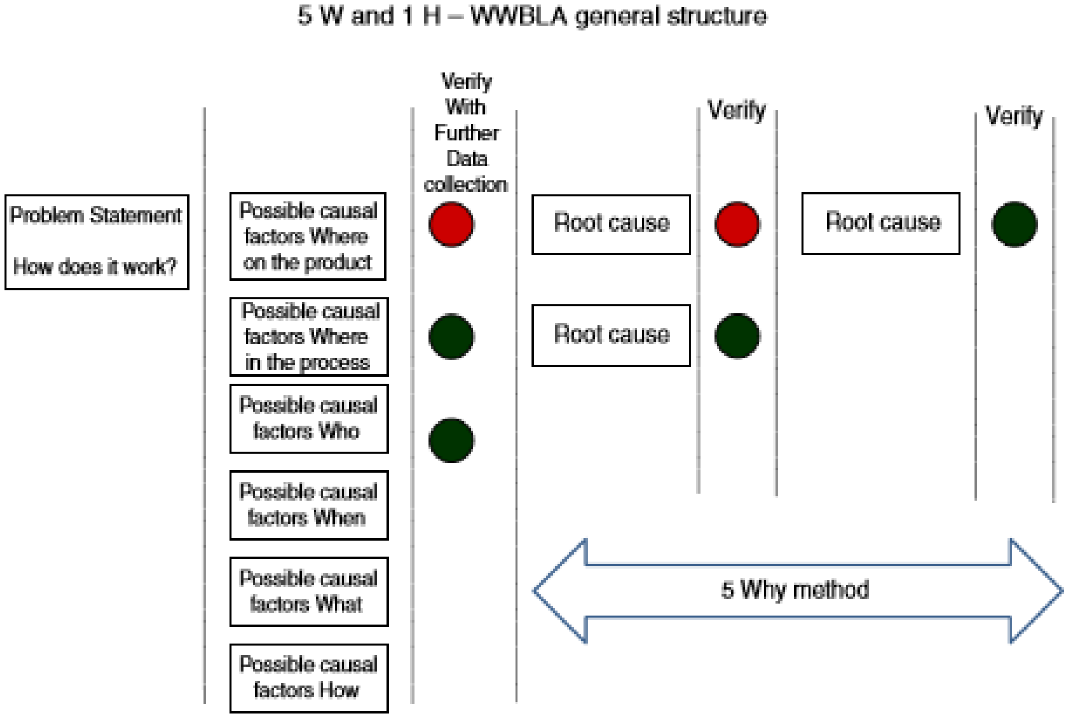


Figure 38: The 5W + 1H – WWBLA concept

With this structure of problem solving, the true root cause may not be able to be determined as to re-create the possible problem condition. However, the structure of 5W+1H, ‘how does it work?’, five why (if necessary) and WWBLA was all fact-based problem solving, and therefore the conclusion from an unsolvable problem will be logical findings but a non-provable root cause with a probability of likelihood. In summary, try to determine the 5W+1H with a single root cause, if this fails, use the five why technique to get to an actionable root cause. If the 5W+1H statement was incomplete, understand ‘how does it work?’ depending on problem complexity and the WWBLA method to determine data collection.

4.4 Issues raised

The problem of poor outcomes from using a problem-solving framework, this includes not solving the problem or increased time to solve the problem by distortion of the process due to opinions and guesses, was raised in the literature review. These problems have been further analysed in this chapter and are the norm for quality problem solving and techniques such as asking why encouraged the inclusion of opinions and guesses. This was also an issue with the initial development of the framework presented in this chapter. This view was supported by Murugaiah (2010) who concludes that the why question may distort responses. Based on the practical applications of the initial 5W + 1H conceptual model and other practical applications not included in this research due to ethical approval. The framework has been developed further and the following section presents the framework. Prior to the discussion of the development of the framework, the weaknesses of the initial 5W + 1H conceptual model are given.

- The How question was not comprehensive in scope to include all possible outcomes.
- The Which question was included but not explained
- The use of the fishbone structure was poorly explained
- The use of the why question was included, as previously mentioned
- The link between 5W + 1H statement and how does it work? was not clearly explained
- The use of the WWBLA was poorly explained
- There were no decision rules to move from one stage to the next stage
- The proposal was described as a concept/model/framework, this was not clear
- No discussion on solutions was given

These weaknesses have been analysed and a further assessment comparing the initial concept with the final framework was presented later in this chapter.

4.5 Framework and detailed process for quality problem solving

This section of the chapter provides the latest development for the framework for quality problem-solving. In doing so the proposed framework, provides a possible solution to fulfil the research gap given by DeMast (2013). The initial 2 stage concept has been expanded to a 4-stage concept based on the analysis of the problems presented. The 4 stages are as follows: -

1. The collection of initial facts. (Fact collection about the problem)
2. An understanding of the machinery or system of work. (How does it work?)
3. The development of an action plan for further data collection (Further data collection)
4. What to do if it is not possible to collect all the facts? (No solution is possible due to missing facts)

The framework was shown in Figure 39. The decision point method was detailed later in the chapter.

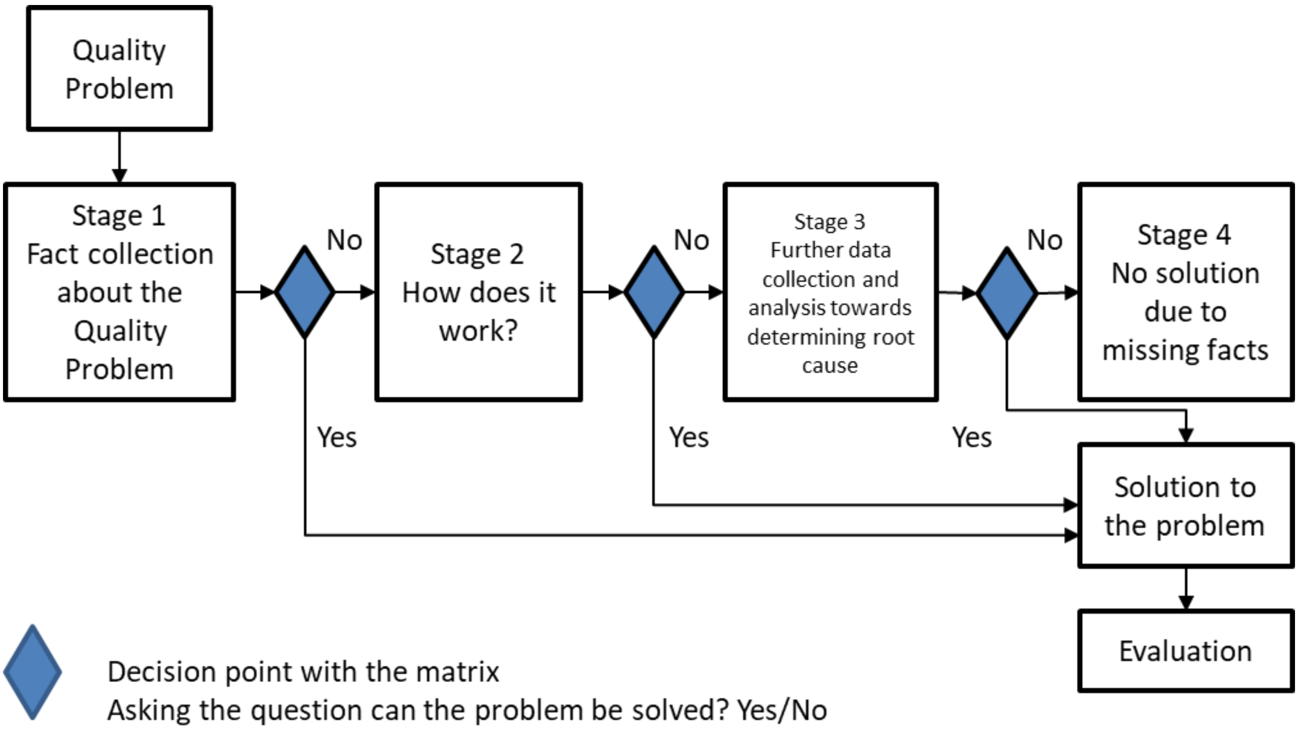


Figure 39: Framework for problem solving

Stage 1 – Fact collection about the problem

As detailed in the introduction, the 'Kipling Method' known as the 5W&1H was the starting point for Stage 1. Unlike the Kipling Method, the use of the 'why' question was removed as discussed throughout the research. It was proposed that the use of the other W questions was useful for the development of Stage 1. The removal of the Why question can be linked back to the literature review and the issues raised with asking why. The series of questions was proposed and should be asked to define the problem, there was no order to ask these questions. It was proposed that to provide clear structure the question should be asked in the same order within this framework: -

W1 - Where on the product is the problem seen?

W2 - Where in the process is the problem seen?

W3 - When did the problem occur?

W4 - What is the trend – discrete or continuous?

W5 - Who saw/created the problem?

W6 - What product/service has the problem?

To provide the link between a definition of quality and the framework to solve quality problems. The further questions are based on the definition of quality, in which, quality is defined as 'on target with minimum variation': -

H1 - How does the problem deviate from target/standard/expectation?

H2 - How much variation about the target/standard/expectation is seen?

After data collection to answer the proposed questions, was it possible to solve the problem? This was a decision and requires some criteria for decision making this is detailed later in the chapter.

The order to the questions was based on empirical evidence. Some of the evidence was given in the examples within the literature review and it suggests that the how questions and where in the process was the problem seen, often hold the key to good problem solving in the initial stage. The author has experience of the framework and the evidence was anecdotal and given as such without structured research. With respect to the how question, differing expectations create problems as do lack of standards. Similarly, understanding the point in the process where the problem was seen, gives a starting point for the process to be traced back to the root cause. However, knowing where to stop the process assessment can be guided by the other questions. Generally, it was also fair to conclude, again from empirical use of the framework, that the greater the time between the problem being seen and its creation will increase the likelihood of not being able to recall the facts of the problem.

Stage 2 – How does it work?

Having completed Stage 1, if it was not possible to solve the problem it will be necessary to collect new data to provide answers to the questions in Stage 1. The second stage, asks the question, 'How does it work?' This stage, will be unique to the problem in hand, therefore, it was not possible to define in general terms. To provide understanding a suitable analogy for 'how does it work?' are the Haynes manuals which provide a breakdown of the inner workings of a car, component by component and how they are linked and function within the car. In undertaking such an assessment, the outcome will be a deeper understanding of the problem. Therefore, the root cause of the problem may be found as a deviation between how it should work? and how it does work? A further approach is the use of pictures/photographs or video, which could be used to understand the function in detail. The ability to film and use slow motion, allows for deeper study of the function. The case studies in Chapter 5 demonstrate this stage.

Stage 3 – Further data collection and analysis towards determining the root cause

This stage of the framework provides a structure for further data collection to collect opinions based on the knowledge gained in the first two stages as to the root cause of the problem. These opinions are then explored by using experiments to determine the facts. The detail of the structure was to list the opinions as to the possible root causes using a tree structure. For example, from the analysis of the process, for the where in the process question, it makes logical sense to check the detail of the process prior to the problem and propose that the settings or conditions in that step are checked for compliance to standard. The structure was shown in Figure 40.

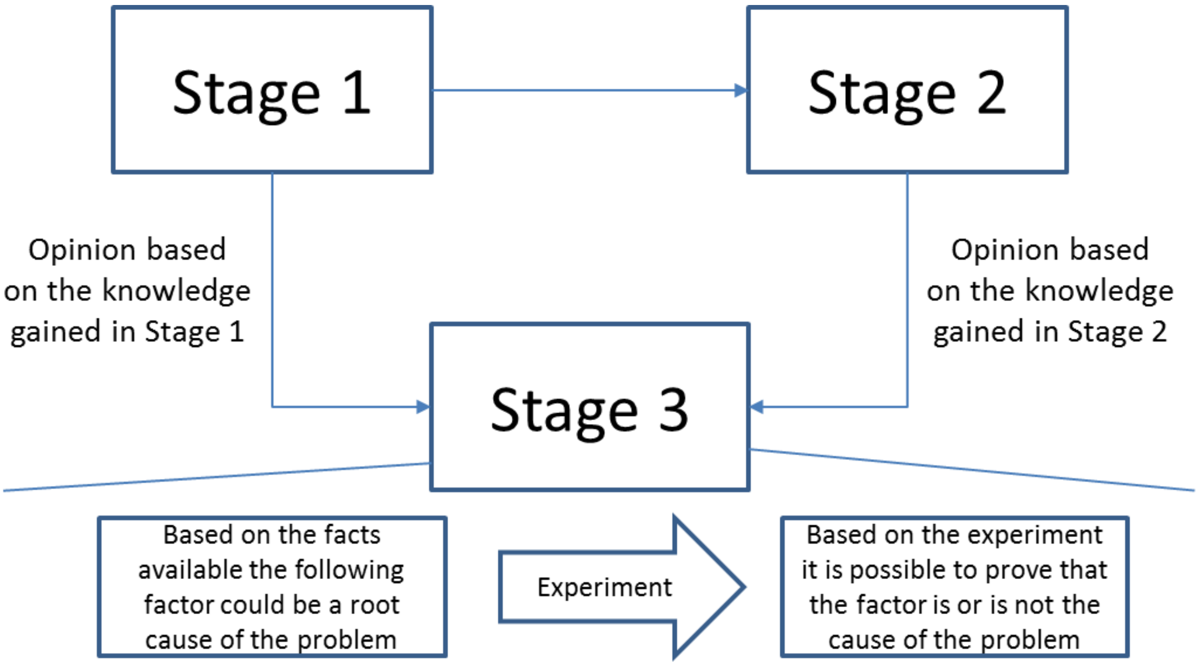


Figure 40: Flow of data between stages

The structure used in Stage 3 was the same as the structure seen in Problem 4 earlier in the Chapter.

Stage 4 – No solution is possible due to missing facts

Some problems are unsolvable and despite collected all the facts, a conclusion that the root cause was unknown should be drawn. It was possible that potential root causes could be defined using probability to provide a likelihood of cause, but the problem would remain unsolved.

Evaluation

Following the solution phase, an evaluation phase was proposed using the techniques detailed in the research method chapter, section 3.2.5. The outcome of this step will be to confirm the improvement or to undertake new research into the problem using the 4 Stage framework.

4.6 Detailed process flow

To support the development of the detailed process flow, in addition to the points raised in the previous section, it was necessary to examine the detailed processes of the frameworks given in the Literature Review. The analysis of the impact of various tools and techniques used within the frameworks was already given in within this chapter. Therefore, the development of the detailed process in this section will avoid the issues raised from the previous analysis and assessment. That was, the use of tools and techniques which encourage the collection of opinions and guesses during the detailed process will be avoided. The development of fact collection will be encouraged, and this may involve the design of an experiment to create 'deviation from target' conditions to understand how the problem has occurred. The starting point for the detailed process, was the link between a definition of quality and the problem-solving process. This absence of a link was a gap established in the literature review. Figure 41 provides a pictorial representation of the wording given in Table 9.

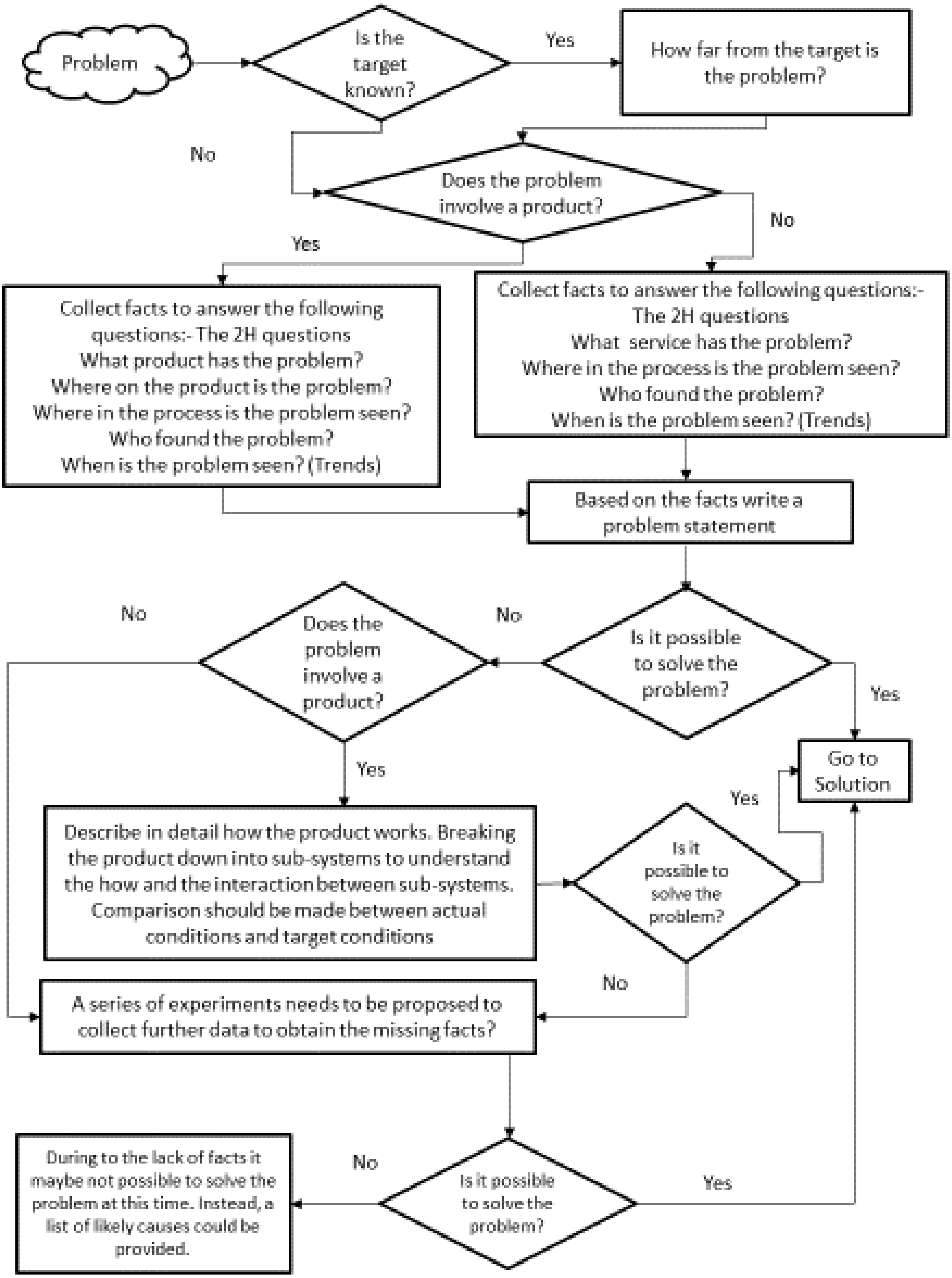
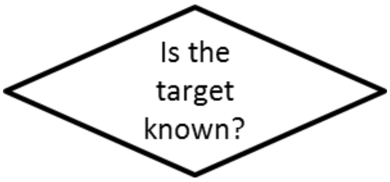
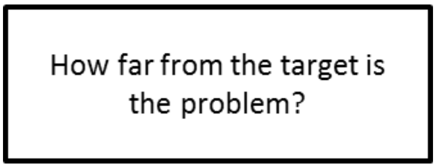
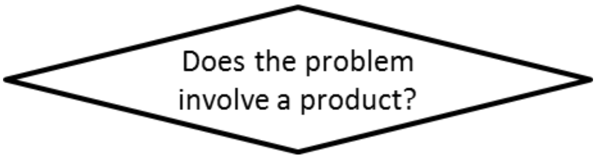
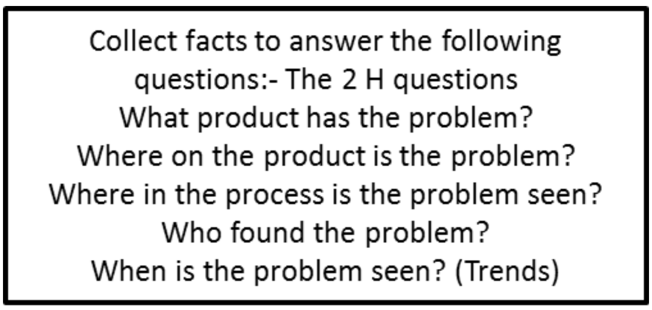


Figure 41: Detailed process flow from problem to solution

To ensure the detailed process, given in Figure 41, is understood each unique step is detailed.

This is presented in Table 9.

Detailed step	Description
1. 	This is the start of the process, there is a problem to be solved using the framework.
2. (Stage 1) 	This is a decision step in the process. The outcome is either yes or no. Within Chapter 2 the need to define a quality problem using a definition of quality is discussed. The use of 'on target with minimum variation' (Taguchi) is discussed. By using this definition as a starting point, it overcomes the shortcoming discussed in the literature review.
3. (Stage 1) 	If the outcome of step 2 is yes, then it will be possible to describe how far from the target the problem is? This will be domain and problem dependent. All problems either product or service can be defined in this manner if the target is known.
4. (Stage 1) 	Step 4 is required to provide a decision point between product and service problems to ensure the appropriate questions are asked.
5. (Stage 1) 	Step 5 is the step in which the facts are collected about the problem, the questions relate to a problem with a product. This is discussed in the literature review were the rationale for not asking the why question is given. These questions narrow the focus to the root cause of the problem as opinions and guesses are not used in the process.

Detailed step	Description
6. (Stage 1) Collect facts to answer the following questions:- The 2 H questions What service has the problem? Where in the process is the problem seen? Who found the problem? When is the problem seen? (Trends)	Step 6 is the step in which the facts are collected about the problem, the questions relate to a problem with a service. This is discussed in the literature review were the rationale for not asking the why question is given. These questions narrow the focus to the root cause of the problem as opinions and guesses are not used in the process.
7. (Stage 1) Based on the facts write a problem statement	Using the facts collected from either step 6 (service) or step 5 (product) and step 3 are used to provide the details for the problem statement. This is final step of Stage 1 in the framework.
8. (End of each stage) Is it possible to solve the problem?	This is a decision point between each stage of the framework. If it is possible to solve the problem at the end of any stage, then the next step is to determine the solution (step 13). If it is not possible to solve the problem, then the next step is to move to the next stage of the framework. The decision rules are discussed following this table.
9. (Stage 2) Does the problem involve a product?	This is a decision rule at the start of Stage 2 to determine whether the problem involves a product or a service. If it is a product problem, then the next step is to go to step 10. If it is a service problem, then the next step is to go to Stage 3.
10. (Stage 2) Describe in detail how the product works. Breaking the product down into sub-systems to understand the how and the interaction between sub-systems. Comparison should be made between actual conditions and target conditions	This step is product dependant; the purpose is to obtain a deep understanding of how a product works against how it was designed to work. In conducting this study, it will be possible to determine deviation(s) from target which could then explain the cause of the problem.

Detailed step	Description
	After this step the next step is step 8.
11. (Stage 3) A series of experiments needs to be proposed to collect further data to obtain the missing facts?	Based on all the information collected from Stage 1 and 2 for a product problem and Stage 1 for a service problem. Stage 3 involves proposing further data collection to obtain a better understanding of the questions given in Stage 1. This may involve controlled experiments to recreate the conditions in which the problem occurred.
12. (Stage 4) During to the lack of facts it maybe not possible to solve the problem at this time. Instead, a list of likely causes could be provided.	It is important to accept that a problem may not be solvable and having collected all the facts and information required by following the framework, it may only be possible to provide a likely cause but not be possible to prove it is the cause as a fact.
13. Go to Solution	The solutions are detailed in section 4.6 of this chapter.

Table 9: The detailed process descriptions

The decision rule given in step 8 operates to provide a rule for either moving to the solution or to stage 2 or 3 or 4. Figure 42 was the decision matrix. The outcome from using the matrix was to obtain correlation between the different questions. The W and H refer to the questions detailed earlier in the chapter, and are shown in the second matrix. It should be possible to write a statement in which, for example, W1 explains W2 and vice versa. In completing the matrix over the stages as necessary it should be possible to determine the root cause and therefore, a solution or solutions which are detailed in the next section.

W1	W1						
W2		W2					
W3			W3				
W4				W4			
W5					W5		
W6						W6	
H1							H1
H2							

W1	W1						
W2	Where(product) & Where(process)	W2					
W3	Where(product) & When	Where(product) & When	W3				
W4	Where(product) & Trend	Where(product) & Trend	When & Trend	W4			
W5	Where(product) & Who	Where(product) & Who	When & Who	Trend & Who	W5		
W6	Where(product) & What	Where(product) & What	When & What	Trend & What	Who & What	W6	
H1	Where(product) & Target	Where(product) & Target	When & Target	Trend & Target	Who & Target	What & Target	H1
H2	Where(product) & Variation	Where(product) & Variation	When & Variation	Trend & Variation	Who & Variation	What & Variation	Target & Variation

Figure 42: The decision matrix

To explain the decision matrix for each stage, Figure 43 was presented, it shows how stage by stage more facts are added and how this is linked to the solutions.

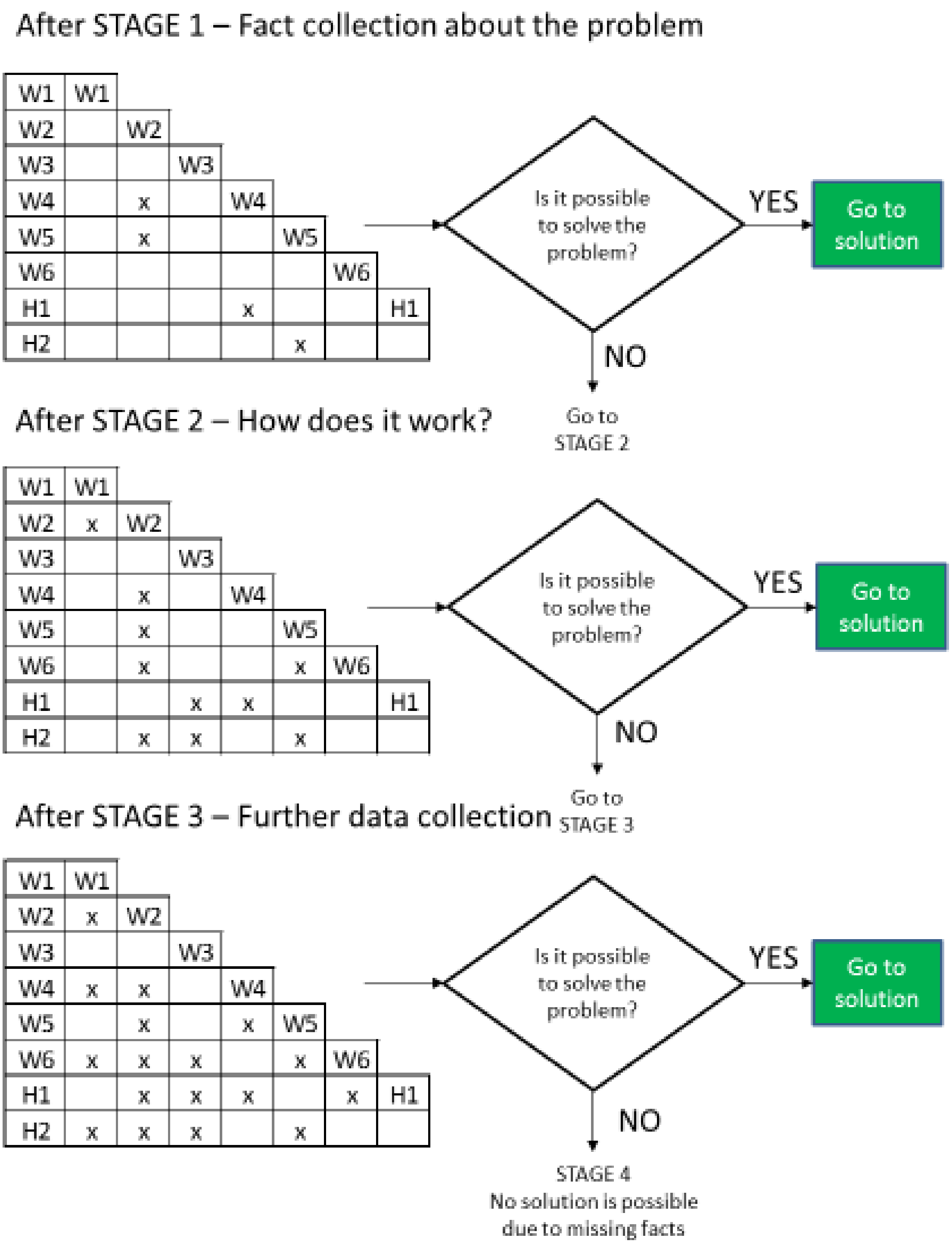


Figure 43: The decision matrix by stage

Table 10 shows the relationship between the findings in the literature review and the framework presented in this section. The letter C indicates a correlation between the proposed framework and the literature review. The justification for the matrix was determined using the proposed framework and a review of the research undertaken in the literature review.

Author's Research	Key steps in the proposed framework	Research from the literature review															
		Definition of Quality - conformance to specification	Definition of Quality - on target with minimum variation	PDSA	PDCA	Kaizen	A3 method	Global 8D	Six Sigma	5 step problem solving pentagon	Why because analysis	4 Wives and 1 husband	Brainstorming	Cause & Effect diagram	Cause & Effect Matrix	5 Whys/Asking Why
	Stage 1 : 5W&1H (no why)		C1			C2	C3	C4		C5		C6				
	Stage 2 : How does it work?						C7									
	Stage 3 : Further data collection										C8					
	Stage 4 : No solution															
	Decision Matrix between each stage								C9							

Table 10: The correlation between the Author's Research and the Literature Review

Footnote to the table

C1 – The definition was used in the How question in stage 1

C2 C6 – Kaizen uses the 4 Wives and 1 husband, and these questions are used in the stage 1

C3, C4, C5 – These questions are used in stage 1 but with the Why question

C7 – Like Stage 2 – Clarify the problem

C8 – Similar structure used

C9 – Decision gate are used in Six Sigma, but it was seen to be a list of tools and techniques completed rather than linked to the problem being solved.

4.7 Solutions

To provide a complete framework which flows from the quality problem to a solution, an explanation for the solution phase was given. By using the definition of ‘on target with minimum variation’ to describe an acceptable level of quality, it was possible to propose questions to ask if a problem occurs, the questions are those given in the framework detailed earlier in the chapter. The counter argument, to this, was to propose a set of general solutions to ensure the target is achieved with minimum variation.

The general solutions are given as follows: -

Removal of the process step causing the problem. Following the use of the problem-solving framework, the root cause was found to be an activity within a process step which can be removed and therefore the problem does not occur again. In a similar way, within a product, a part was found to be broken and by replacing the part the problem does not occur again.

The use of a Poke-Yoke solution to ensure the process can only function in the correct way and all other options are not possible, therefore, no variation only 100% achievement of the target. Fisher (1999) explains that the Poke-Yoke method is a technique for avoiding simple human errors at work.

If it was not possible to introduce a solution which removes the variation, it will be necessary to monitor the process to ensure future use of the process was acceptable with respect to target and variation. This may involve 100% inspection, or an inspection plan based on the analysis of the process data.

If monitoring of the process starts to reveal a pattern in the variation which becomes too large against the target, the variation creates problems which results in a cost problem. In this situation, the process would require re-design. The framework could be used to define the problem for the re-design. In all these solution outcomes, there was the need to have a detailed work or training instructions to ensure the solution is implemented and maintained.

Figure 44 was given to visualise the solutions detailed in this section.

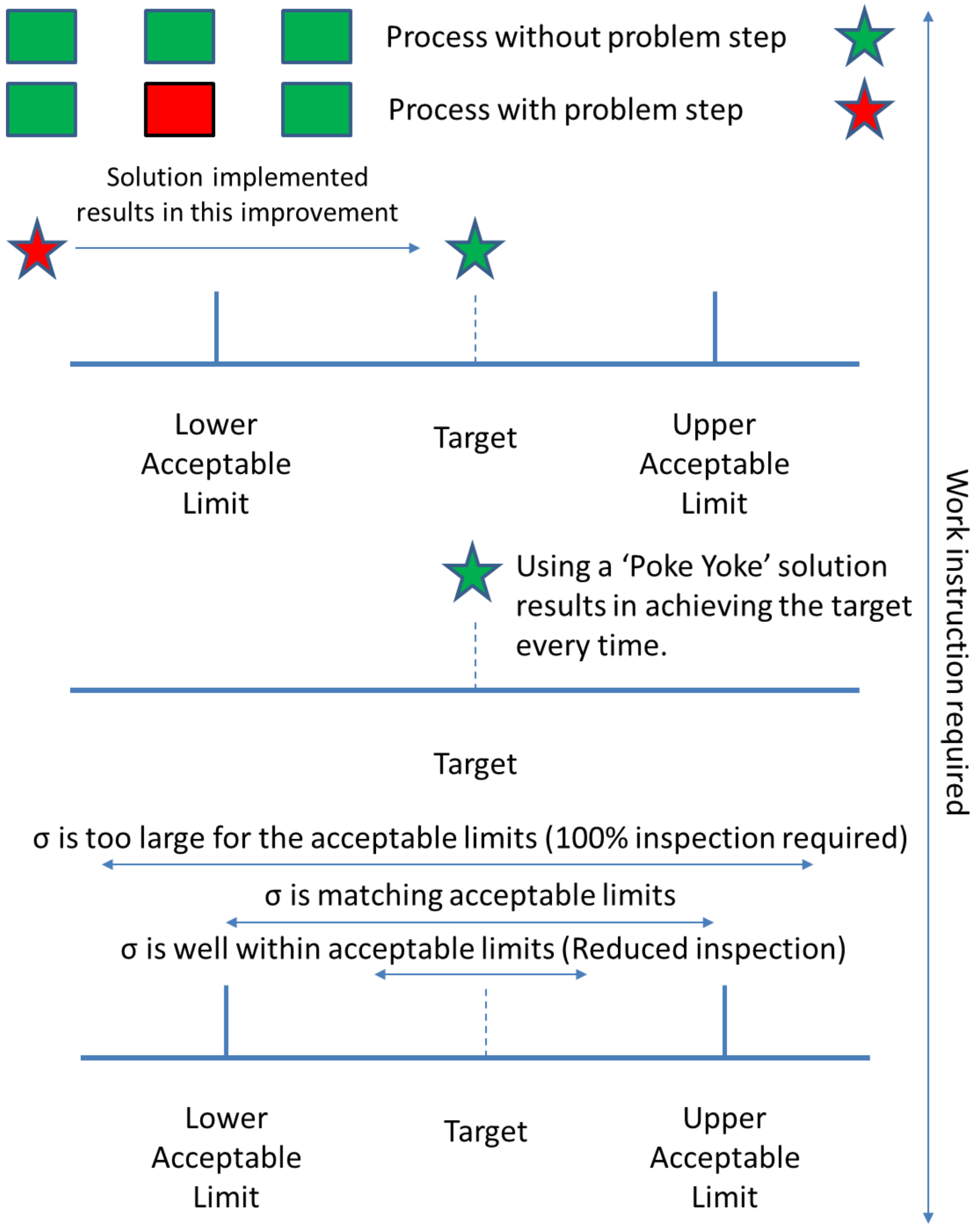


Figure 44: The solutions visualized

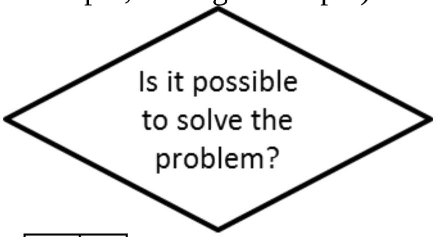
The stars in Figure 44, represent the following, the red star represents the problem and the green star represents the ideal solution.

In the next chapter, the case studies follow the detailed process and a solution was presented for each case study. The case studies follow Table 11 which was the detailed process for a product quality problem. A topic for further research was the application of the framework to service problems. This was considered in the final chapter.

Product problem – detailed process	Data collection
1. Problem	
2. (Yes – go to step 3, No – go to step 4) Is the target known?	
3. How far from the target is the problem?	
4. Collect facts to answer the following questions:- The 2 H questions What product has the problem? Where on the product is the problem? Where in the process is the problem seen? Who found the problem? When is the problem seen? (Trends)	
5.	

Based on the facts write a problem statement

6. (Yes – go to step 7, No – go to step 8)



W1	W1						
W2		W2					
W3			W3				
W4				W4			
W5					W5		
W6						W6	
H1							H1
H2							

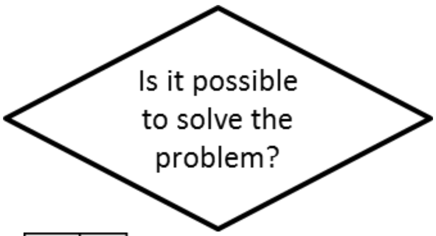
7. (Implement and collect data to prove the solution)

Go to Solution

8.

Describe in detail how the product works. Breaking the product down into sub-systems to understand the how and the interaction between sub-systems. Comparison should be made between actual conditions and target conditions

9. (Yes – go to step 10, No – go to step 11)



W1	W1						
W2		W2					
W3			W3				
W4				W4			
W5					W5		
W6						W6	
H1							H1
H2							

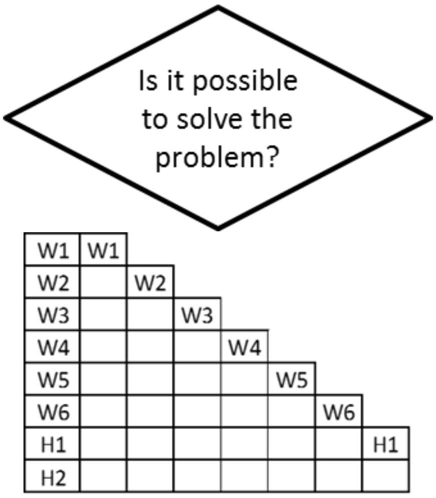
10. (Implement and collect data to prove the solution) Go to Solution	
11. A series of experiments needs to be proposed to collect further data to obtain the missing facts?	
12. (Yes – go to step 13, No – go to step 14) 	
13. (Implement and collect data to prove the solution) Go to Solution	
14. During to the lack of facts it maybe not possible to solve the problem at this time. Instead, a list of likely causes could be provided.	

Table 11: The detailed process for a product problem

4.8 Comparison between the RCA – 5W&1H concept and the 4-stage framework

As detailed within this chapter, weaknesses with the initial RCA – 5W&1H concept was discussed. Table 12 compares RCA – 5W&1H concept and the 4-stage framework in this research.

RCA-5W&1H concept	**Proposed framework**	**Development over the period of research**
(Reid & Smyth-Renshaw 2012)	based on the literature review	
5W&1H procedure	Stage 1 - Not asking why?	
What product/service? The description of the product or service that has experienced the problem, if several products are using a common process and only one is experiencing a problem, and then the root cause could be the design of the product. It is unlikely that for a service problem, this question would yield any information other than the name of the process.	What product/service? This is the same as the RCA-5W&1H concept	Fundamental process step for the latest framework
Who? This question is aimed at determining the people who are present at the time of the problem.	Who? This is the same as the RCA-5W&1H concept with the additional question of who created the problem?	Additional question of who created the problem
When? This question is concerning the timing of the problem; further, it is possible to examine possible trends in the problem occurrence. If a problem has a trend, for example, the problem occurs every Monday at 11 AM, this is very important in the problem-solving process.	When? This is the same as the RCA-5W&1H concept What is the trend – discrete or continuous?	Removal of the which question as it can be determined from the when question.

Where in the process? This question is concerned with the step in the process 'where' the problem is seen. It is important to understand where in the product/service life cycle or process the problem has occurred, which is likely to involve mapping the process to answer this question.	Where in the process? This is the same as the RCA-5W&1H concept in addition the importance of where in the process when looking at service problems has been highlighted.	The importance of the where in the process for service problems has been highlighted (This is highlighted as future research)
Where on the product? This is the position on the product 'where' the problem is seen. If the problem is only seen in one position. the root cause is likely to be easier to determine that a product with multiply problems are seen in various positions across the product.	Where on the product? This is the same as the RCA-5W&1H concept and in additional that this question is not needed with a service problem.	Question not required for Service problems (This is highlighted as future research)
How is the deviation from target? The product or service should have a standard target condition which is the ideal condition. This target could be known as perfect quality. The aim of this question is to describe the deviation from this target.	How does the problem deviate from expectation/target/standard? How much variation about the target/standard/expectation is seen?	This question has been split into two components - target and variation
	Stage 2	
How does it work?	**How does it work?**	
Having used the 5W&1H as detailed in the previous section, defining the problem may require a deeper analysis. This is often the cases in either a complex service or a product, which is often useful to try to describe how a product or service should work or operate. Therefore, for a	How does it work? - this is the second tier of the proposed framework and relates only to problems with a product. The principle is the same as the RCA concept in which products are broken down into sub assemblies to understand the function and fit of the individual parts. For service problems the need to map the process in detail is now recommended in the first tier of the framework - Where in the process?	Fundamental process step for the latest framework

product, this would involve a breakdown of any assemblies into parts to examine the function and fit of the parts. For a service, the situation is different, and the use of process mapping would be required to understand the service function.		
The ‘why’ question will review an example of how a current state can be scrutinised using a fault tree approach to get to root cause and how to verify the cause-and-effect relationships, cost implications and gap elimination techniques. In this study, the fishbone diagram represents the 5W&1H methodology as the foundation to the RCA. Another alternative could be listing the causes against the 5W&1H headings. The ideal target now is to have one actual root cause on the fishbone structure, or failing this a root cause where the five why method can be used to get to a root cause that can be undertaken to remove the root cause.	The 'why' question and the use of the cause and effect diagrams is not used in the proposed framework.	Removed from the proposed framework
	Stage 3 - Establishing Facts	
N/A	This stage of the framework provides a structure for further data collection, in particular, to collect opinions based on the knowledge gained in the first two stages as to the root cause of the problem. These opinions are then explored by using experiments to determine the facts. The detail of the structure is to list the	New step

	opinions as to the possible root causes using a tree structure.	
	Stage 4 - not solvable	
N/A	Some problems are unsolvable and having collected all the facts, it may be possible to conclude that the root cause is unknown. The possible root cause could be defined as a probability of likelihood of root cause, but the problem would remain unsolved.	New step
Decision matrix		New step
Evaluation		New step

Table 12: The comparison between RCA concept and the framework within this chapter

The addition of the step for solutions addresses a weakness given in the earlier list. The final element of the research was the proposal of a conceptual model by which any quality problem-solving framework including those detailed in the literature review can be further evaluated. The importance of this proposal was seen in the analysis in Chapter 5.

4.9 The development of a conceptual model

The question of how to compare quality problem solving frameworks was raised during the research. It was considered the third research question. The issue was the design of a research method using a single quality problem and multiply techniques. The major problem was human learning as the quality problem-solving process evolves. These issues are some of the factors considered in the development of the conceptual model.

What is a conceptual model? A literature review reveals the following; a way to represent the social and physical world aspects for understanding and communicating according to

Mylopoulos (1992). Misic and Zhao (2000) propose that the right choice of reference models helps to minimise possible mistakes in the early modelling phases. Bodart et al. (2001) provide a theory to predict the attributes and relationships to be considered in a conceptual model when the domain understanding is represented by conceptual schemata. Siau (2004) defines conceptual modelling as the process of formally documenting a problem domain for understanding and for communication among stakeholders. Moody (2005) evaluates the conceptual model quality for its approaches to reality which is relevant for users, but finds, there is no common standard for conceptual model quality. Gemino and Wand (2005) show the existing difficulty to strike a balance between the simple and complex, between quality and quantity, when it is required to transmit some information, conceptual modelling can be used to address complexity. Hernández et al. (2008) point to the generation of conceptual models becoming more important for the design and analysis of processes. Figure 45 shows a proposed conceptual model for solving a quality problem.

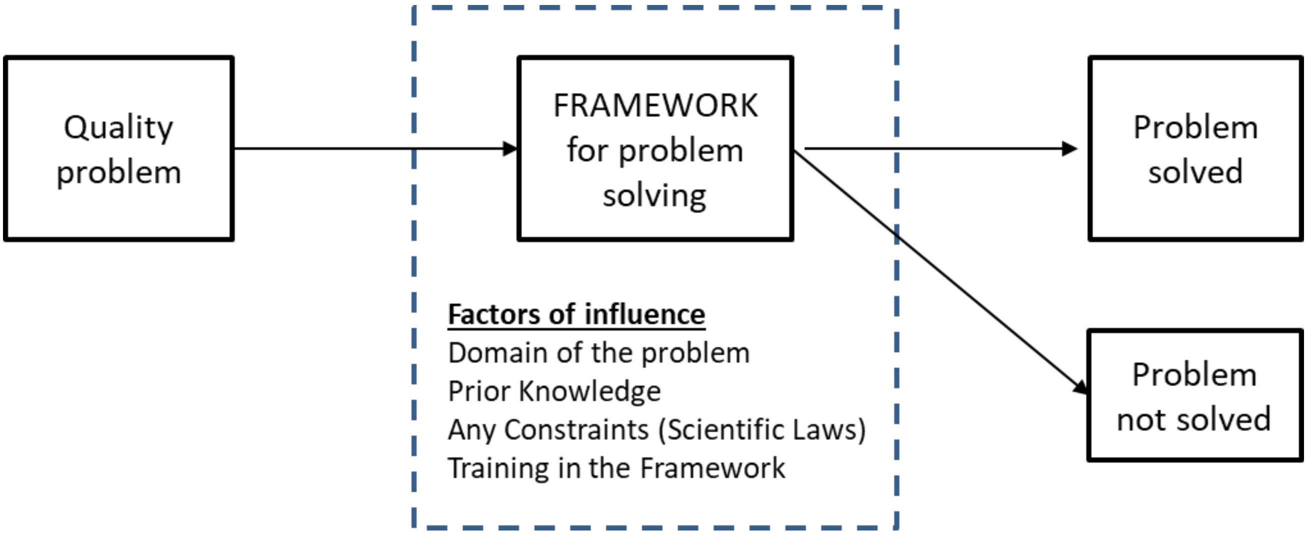


Figure 45: Conceptual model for problem solving frameworks

The explanation for the model was as follows, prior to quality problem happening there was all the prior knowledge which was linked to the domain in which the problem has occurred. The use of any quality problem-solving framework will be influenced by the following factors:

- the nature of the problem, any constraints, the understanding of the framework and the timeframe in which any prior knowledge was introduced into the framework. These inputs will determine whether the quality problem was solved. As discussed in the literature review, all the frameworks considered in the literature review can be considered within this conceptual model and evaluated against the influencing factors to determine if the outcome, the quality problem was solved, was achieved. Within the literature review, it was established that all the existing frameworks used tools/techniques which encourage the user to collect opinions and guesses as part of quality problem solving process, often via brainstorming the problem. This approach fits the conceptual model as the timeframe in which prior knowledge was used in the quality problem-solving framework. The influence of the domain is difficult to determine without conducting a wider study across a range of domains to test the suitability of the framework. Approaches such as Six Sigma, which have been widely trained, do have application in a wide range of domains. It was fair to conclude that longevity of the framework will result in a greater application across a greater number of domains. However, it was not possible to test this claim in this research. The other input factor which was the constraints was important as this provides the boundary for the quality problem which was the physical scientific laws which govern nature, for example gravity (Natural phenomena), the laws of motions (Newton) and the properties of chemical elements (e.g. Boyles Law). It was important that any framework considers the scientific laws which govern the quality problem. Using the review of conceptual models, and evaluating whether the model in Figure 45 matches the criterion of a conceptual model. In that it, provides the design of the process (Hernandez et al (2008)), addresses complexity (Gemino and Wand (2005)), is unique (Moody (2005)), ensures understanding (Siau (2004) and Mylopoulos (1992)), defines relationships (Bodart et al (2001)) and prevents mistakes to ensure understanding (Misic and Zhao (2000)). This conceptual model can be linked to Figure 4 within the literature review, the process step described as ‘failure’ would be the ‘framework for problem solving’ within the conceptual model.

4.10 Summary of the chapter

Chapter 2 highlighted the research gaps. These were that tools and techniques which allow the user to include opinion and guesses could distort the quality problem solving process. This was driven by using the ‘why’ question, in the quality problem-solving process. This chapter describes a conceptual model and a detailed process flow for defining and solving quality problems with production of products. The development of the solution was described in detail; it follows a process from an initial conceptual model through to a fully detailed process. To support the development from conceptual model to detailed process flow, a literature review was included using suitable and appropriate references. The development includes a comparison between a paper published in 2012, during the time of this research and the findings of the examples given in this chapter. This comparison was then further developed with an analysis of current techniques and a rationale for the use of defining a quality problem as the level of deviation from target. Having completed this analysis, it was possible to define the step by step detailed process, which was the contribution to knowledge. To enhance the framework from problem solving only, to a complete process, the topic of solutions is discussed and included and added to the detailed process. This was the author’s full contribution to knowledge. The next chapter uses the step by step detailed process with primary data, using two case studies which describe unsolved problems and demonstrates how the framework and detailed process is used to solve the quality problems.

CHAPTER 5

CASE STUDIES USING THE QUALITY PROBLEM SOLVING FRAMEWORK

5.1 Introduction

The literature review details that, ‘studies of how experienced and successful problem solvers work, may enrich the theory about diagnostic problem solving’ (DeMast 2013). Chapter 4 provided a framework for quality problem solving, to enrich the theory of problem solving with a focus on quality problems. The framework was based on the research gaps determined in the literature review, Chapter 2. Within this chapter, the framework has been used to solve two different quality problems, these are presented as two case studies. A conceptual model for quality problem solving frameworks was discussed after the presentation of the case studies. Chapter 3, the research method, provides the detail of the structure for this chapter, in Section 3.3. The case studies have been given not to address any of the research questions but to provide a demonstration of the framework given in the previous chapter. The research to support the reliability and validity was discussed in the section on further research in Chapter 5.

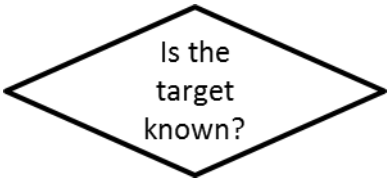
5. 2 Case study 1: Flow Products Ltd (Source: Flow Group PLC)

5.2.1 Introduction to the Company

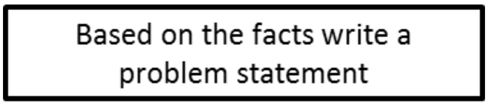
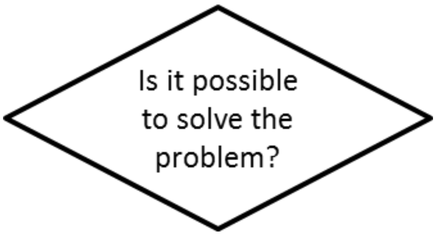
Founded in 1997 and incorporated in the UK, Flowgroup (formerly Energetix Group) specialises in developing and commercialising products to meet energy needs. Whilst the company’s main operations are in the UK, the demand for energy technology is global. The mission of the company is to create a global technology-led company that takes advantage of the worldwide heating, energy and connected home markets. Following UK success with its electricity-generating Flow boiler, the Group will expand overseas, developing a range of products on the foundation of its patented microCHP technology platform. The model is that UK customers can receive a revolutionary Flow boiler at no cost apart from installation. In return, they agree to receive their gas and electricity from Flow for five years. Over those five years, the customer pays for all their gas and electricity as normal. The value of the electricity the boiler generates pays for the boiler over five years, while Flow earns a margin from energy supply. After those five years, Flow shares the generation revenue with the customer for another five years. This is an attractive proposition for most customers, helping them to avoid the large one-off cost of replacing a boiler and helping them reduce rising energy bills. It's a unique way to attract high value, long term energy customers.

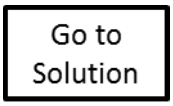
5.2.2 The raw data

This section provides a summary of the raw data collected from the Flow Group, the questionnaire has been used in the data collection process. The questionnaire is shown in Appendix 2. Using Table 11 from the previous chapter to present and detailed problem-solving process with the decision rules to obtain the solution.

Product problem – detailed process	Data collection
1. 	The initial problem was to minimize the number of unscheduled, less than 12-month service calls by minimizing the water loss in the system. Flow Products Ltd are accruing $80000 for every week of lost production.
2. (Yes – go to step 3, No – go to step 4) 	The initial target was to minimize water loss to less than 50ml.
3.	How – Water loss should be no more that 50ml at the end of the

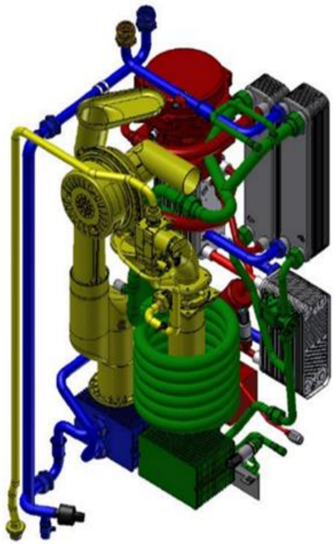
How far from the target is the problem?	5 days PPB V&V test. 19 of the 22 units exceed this value.
4. Collect facts to answer the following questions:- The 2 H questions What product has the problem? Where on the product is the problem? Where in the process is the problem seen? Who found the problem? When is the problem seen? (Trends)	What – The 14kW/H1.0 mCHP appliance Who – The Validation Manager discovered the failure. Where in the process – The appliances fail the 5 days PPB (Pre-Production Build) V&V (Validation and Verification Test) Where on the product – The problem was seen in the steam circuit as excess water leakage. When – unknown. The problem was only detected at the end of the process when the water loss is measured. The failure rate was near epidemic with 19 failures out of 22 units V&V tested.

<table>
<tr><td></td><td></td></tr>
<tr><td>5.

</td><td>The problem statement was given as, 19 from 22 boilers tested for water loss after 5 days fail to meet the target requirement. The problem was seen in the steam circuit by the Validation Manager.</td></tr>
<tr><td>6. (Yes – go to step 7, No – go to step 8)


<table>
<tr><td>W1</td><td>W1</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>W2</td><td></td><td>W2</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>W3</td><td></td><td></td><td>W3</td><td></td><td></td><td></td><td></td></tr>
<tr><td>W4</td><td></td><td></td><td></td><td>W4</td><td></td><td></td><td></td></tr>
<tr><td>W5</td><td></td><td></td><td></td><td></td><td>W5</td><td></td><td></td></tr>
<tr><td>W6</td><td></td><td></td><td></td><td></td><td></td><td>W6</td><td></td></tr>
<tr><td>H1</td><td></td><td></td><td></td><td></td><td></td><td></td><td>H1</td></tr>
<tr><td>H2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table></td><td>Based on this problem statement it was not possible to solve the problem. The decision matrix was shown.
<table>
<tr><td>W1</td><td>W1</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>W2</td><td></td><td>W2</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>W3</td><td></td><td></td><td>W3</td><td></td><td></td><td></td><td></td></tr>
<tr><td>W4</td><td></td><td></td><td>x</td><td>W4</td><td></td><td></td><td></td></tr>
<tr><td>W5</td><td></td><td></td><td>x</td><td>x</td><td>W5</td><td></td><td></td></tr>
<tr><td>W6</td><td></td><td></td><td>x</td><td>x</td><td>x</td><td>W6</td><td></td></tr>
<tr><td>H1</td><td></td><td></td><td>x</td><td>x</td><td>x</td><td>x</td><td>H1</td></tr>
<tr><td>H2</td><td></td><td></td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td></tr>
</table></td></tr>
<tr><td>7. (Implement and collect data to prove the solution)

</td><td></td></tr>
<tr><td>8.</td><td>The CAD model (below) shows a view of the steam circuit within the 14kW/H1.0 mCHP appliance. The steam circuit is indicated in green. Steam travels from PHE Coil - Top (Primary heat exchanger) to parallel connection to Boost Heat</td></tr>
</table>

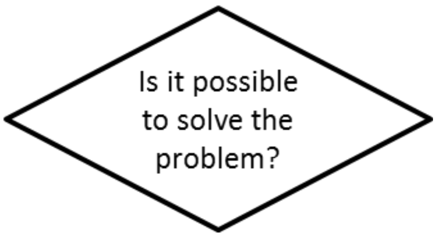
Describe in detail how the product works. Breaking the product down into sub-systems to understand the how and the interaction between sub-systems. Comparison should be made between actual conditions and target conditions

Exchanger (right) and Evaporator (left) to parallel connection (boost valve on Boost Heat Exchanger) to RM11 Heat Exchanger to PHE Coil – Bottom.



Steam circuit (shown in red)

9. (Yes – go to step 10, No – go to step 11)



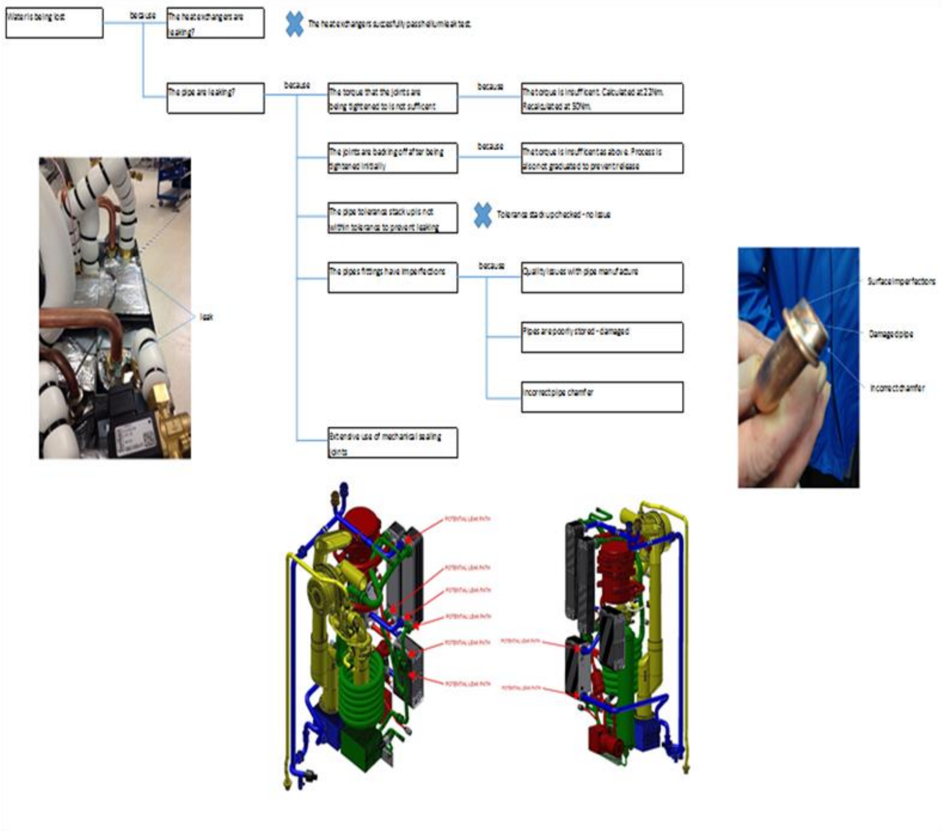
W1	W1						
W2		W2					
W3			W3				
W4				W4			
W5					W5		
W6						W6	
H1							H1
H2							

After completing this assessment, it was not possible to solve the problem. The decision matrix is shown.

W1	W1						
W2		W2					
W3			W3				
W4			x	W4			
W5			x	x	W5		
W6			x	x	x	W6	
H1			x	x	x	x	H1
H2			x	x	x	x	x

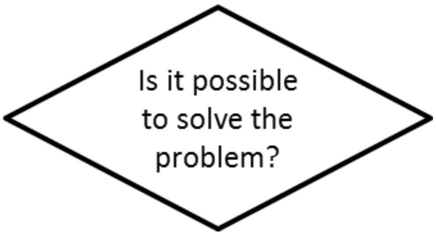
10. (Implement and collect data to prove the solution)

Go to Solution	
11. A series of experiments needs to be proposed to collect further data to obtain the missing facts?	A list of logical causes was obtained and following a series of experiments the root cause was determined. There were several root causes: - The torque was insufficient. It was 22Nm and was recalculated to 50Nm. The pipes fittings have imperfections including pipes are damaged and the pipe chamfers are incorrect Extensive use of mechanical seating joints.



The experimental structure

12. (Yes – go to step 13, No – go to step 14)

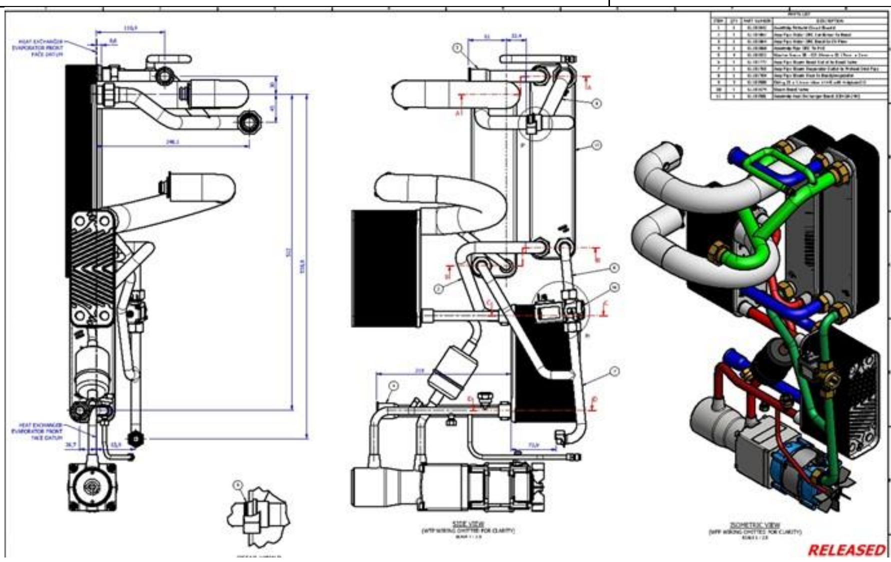


W1	W1						
W2		W2					
W3			W3				
W4				W4			
W5					W5		
W6						W6	
H1							H1
H2							

Following this stage, the root cause of the problem was discovered, and the solution implemented. The decision matrix was complete following Stage 1, 2 and 3.

W1	W1						
W2	x	W2					
W3	x	x	W3				
W4	x	x	x	W4			
W5	x	x	x	x	W5		
W6	x	x	x	x	x	W6	
H1	x	x	x	x	x	x	H1
H2	x	x	x	x	x	x	x

<table>
<tr><td>13. (Implement and collect data to prove the solution)

Go to Solution</td><td>The drawing of the boiler is shown below. To ensure the root causes of the problem are addressed the drawing is changed to incorporate the solutions. This will ensure any new boilers are built without the problems seen in the steam circuit.</td></tr>
<tr><td colspan="2">

Drawing changes</td></tr>
<tr><td>14.

During to the lack of facts it maybe not possible to solve the problem at this time. Instead, a list of likely causes could be provided.</td><td></td></tr>
</table>

5.2.3 The measurement of improvement and validation of the outcome

Prior to using the 4 Stage framework, data regarding the level of leakage within the unit has been collected and recorded and was presented in Table 13. Table 14 shows the data post the use of the 4 Stage framework.

Metrics - Raw Data (Pre leak fix)					
	Appliance	Power Module	Started testing	Steam Circuit leak 5 day V&V (ml)	Pass/Fail
PPB	AN102000.GV01.024715000107	PM102100.DV02.004715000102	21/11/2015	590	FAIL
	AN102000.GV01.024715000106	PM102100.DV02.004715000101	21/11/2015	300	FAIL
	AN102000.GV01.024715000104	PM102100.DV02.004715000098	22/11/2015	200	FAIL
	AN102000.GV01.024715000105	PM102100.DV02.004715000100	22/11/2015	40	PASS
	AN102000.GV01.024715000109	PM102100.DV02.004715000103	30/11/2015	290	FAIL
	AN102000.GV01.024715000108	PM102100.DV02.004715000105	30/11/2015	150	FAIL
	AN102000.GV01.024715000111	PM102100.DV02.004715000104	30/11/2015	150	FAIL
	AN102000.GV01.024715000103	PM102100.DV02.004715000107	30/11/2015	260	FAIL
	AN102000.GV01.024715000112	PM102100.DV02.004715000106	30/11/2015	100	FAIL
	AN102000.GV01.024715000115	PM102100.DV02.004715000110	09/12/2015	410	FAIL
	AN102000.GV01.024715000114	PM102100.DV02.004715000109	09/12/2015	210	FAIL
	AN102000.GV01.024715000110	PM102100.DV02.004715000099	09/12/2015	150	FAIL
	AN102000.GV01.024715000113	PM102100.DV02.004715000108	10/12/2015	220	FAIL
	AN102000-JV00.000516000123	PM102100-EV00-000416000112	10/02/2016	190	FAIL
	AN102100-JV00.000516000126	PM102100-EV00.000416000113	11/02/2016	300	FAIL
	AN102000-JV00.000516000124	PM102100-EV00.000416000114	12/02/2016	200	FAIL
	AN102000-JV00.000516000130	PM102100-EV00.000416000115	16/02/2016	10	PASS
	AN102000-JV00.000516000131	PM102100-EV00.000416000116	16/02/2016	490	FAIL
	AN102000-JV00.000516000125	PM102100-EV00.000616000117	19/02/2016	290	FAIL
	AN102000-JV00.000616000135	PM102100-EV00.000616000123	19/02/2016	280	FAIL
	AN102000-JV00.000516000128	PM102100-EV00.000616000121	20/02/2016	250	FAIL
	AN102000-JV00.000516000129	PM102100-EV00.000616000119	20/02/2016	50	PASS

Table 13: The data prior to using the 4-stage framework

Metrics - Raw Data (Post leak fix)					
	Appliance	Power Module	Started testing	Steam Circuit leak 5 day V&V (ml)	Pass/Fail
PPB	AN102000-JV00.000516000125	PM102100-EV00.000616000117	25/02/2016	20	PASS
	AN102000-JV00.000616000135	PM102100-EV00.000616000123	25/02/2016	20	PASS
	AN102000-JV00.000516000128	PM102100-EV00.000616000121	25/02/2016	0	PASS
	AN102000-JV00.000516000129	PM102100-EV00.000616000119	25/02/2016	10	PASS
	AN102000-JV00.000516000127	PM102100-EV00.000616000120	09/03/2016	50	PASS
	AN102000-JV00.000516000133	PM102100-EV00.000616000122	09/03/2016	40	PASS
	AN102000-JV00.000616000134	PM102100-EV00.000616000118	10/03/2016	0	PASS
	AN102000-JV00.000616000138	PM102100-EV00.000716000125	11/03/2016	30	PASS
	AN102000-JV00.000616000142	PM102100-EV00.000716000137	16/03/2016	0	PASS
	AN102000-JV00.000716000157	PM102100-EV00.000816000159	16/03/2016	0	PASS
	AN102000-JV00.000816000160	PM102100-EV00.000816000150	16/03/2016	0	PASS
	AN102000-JV00.000816000161	PM102100-EV00.000816000156	16/03/2016	0	PASS

Table 14: The data post using the 4-stage framework

The data pre- and post- use of the 4-Stage framework given in Tables 13 and 14 respectively have been used to analysis the effectiveness of the framework using the analysis methods detailed in Chapter 3.

The Statistical Process Control (SPC) chart in Figure 46 shows the leakage rates. The improvement follows the application of the framework which can be seen in the chart from unit 22 onwards.

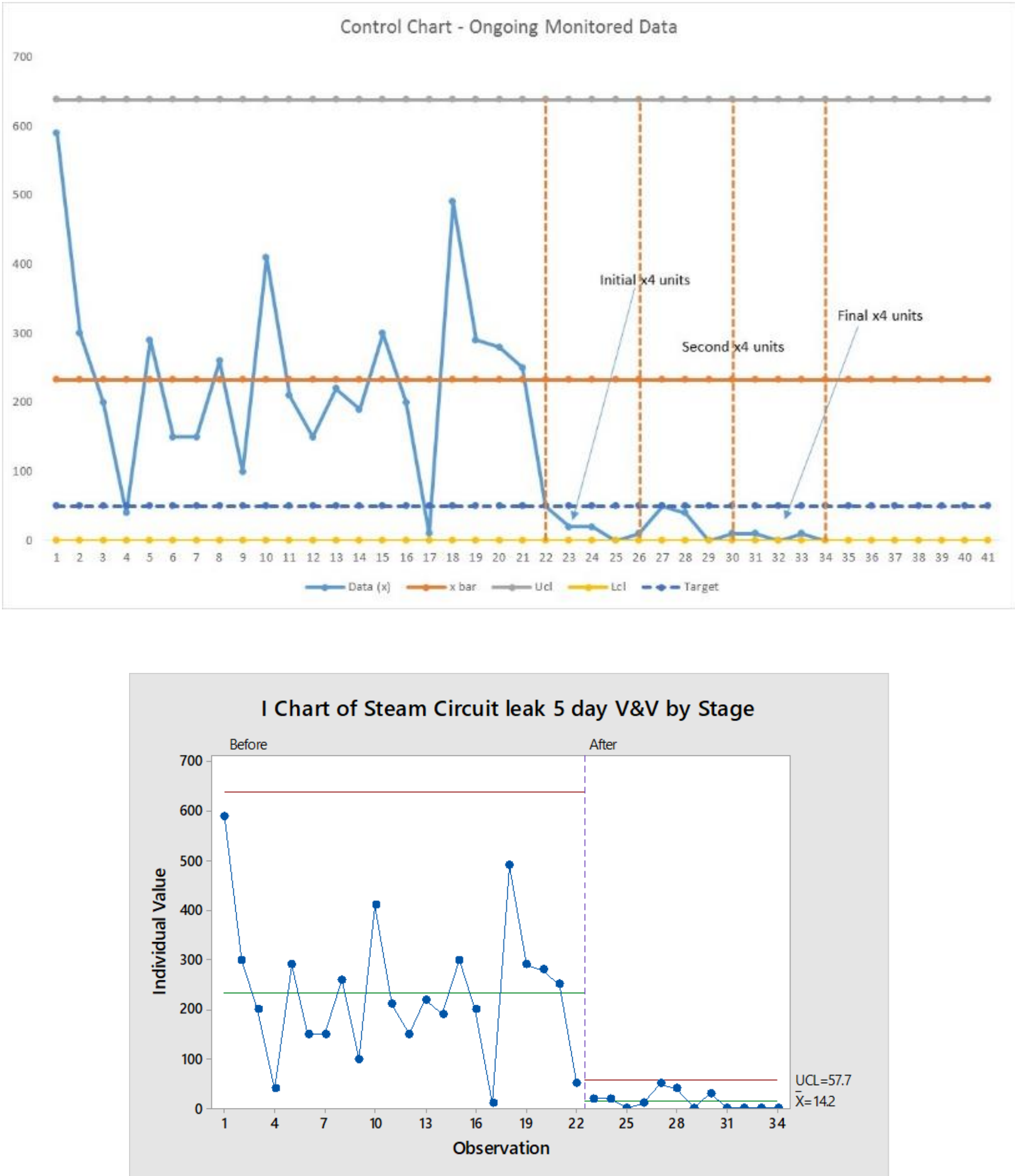


Figure 46: SPC charts using Excel(Top) and Minitab(Bottom)

(X axis is the unit, Y axis is the level of leakage)

The initial DPMO (defects per million opportunities) was 863636 (19 defects from 22 units). DPMO was detailed in the research method, and using a leakage rate of 50 ml as the cut-off point between defect or not; an improvement was seen. The DPMO was zero (0 defects from 12 units) following the implementation of the solution.

Figure 47 shows the cumulative average for before and after, both plots show that the cumulative average has a consistent level trend. This indicates that the process observed was consistent and the data was valid sample of the underlying process. It is important to note that the cumulative average has reduced by a factor of 10.

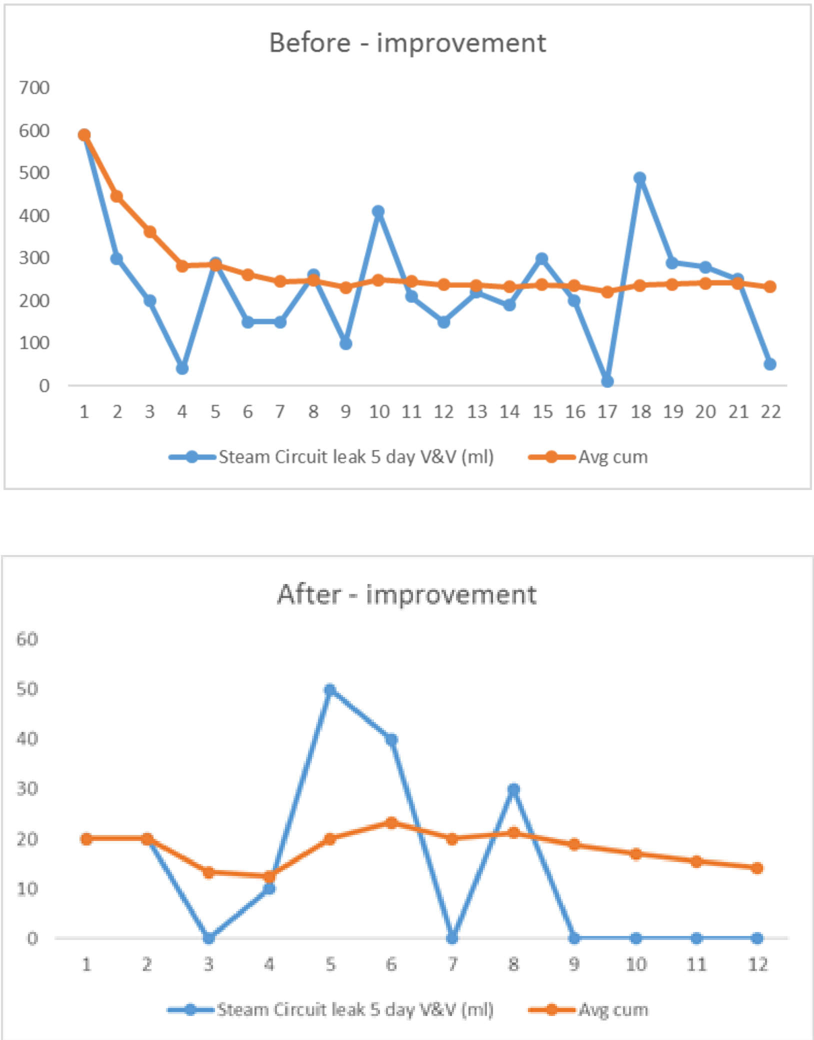


Figure 47: Cumulative average plot for before and after data

(X axis – the unit number Y axis – the leakage (units ml))

A 2 P hypothesis test has been conducted using Minitab statistical software, with the following hypothesis.

Null hypothesis: Proportion defect before = Proportion defect after

Alternative hypothesis: Proportion defect before ≠ Proportion defect after

The outcome of the analysis is shown in Figure 48.

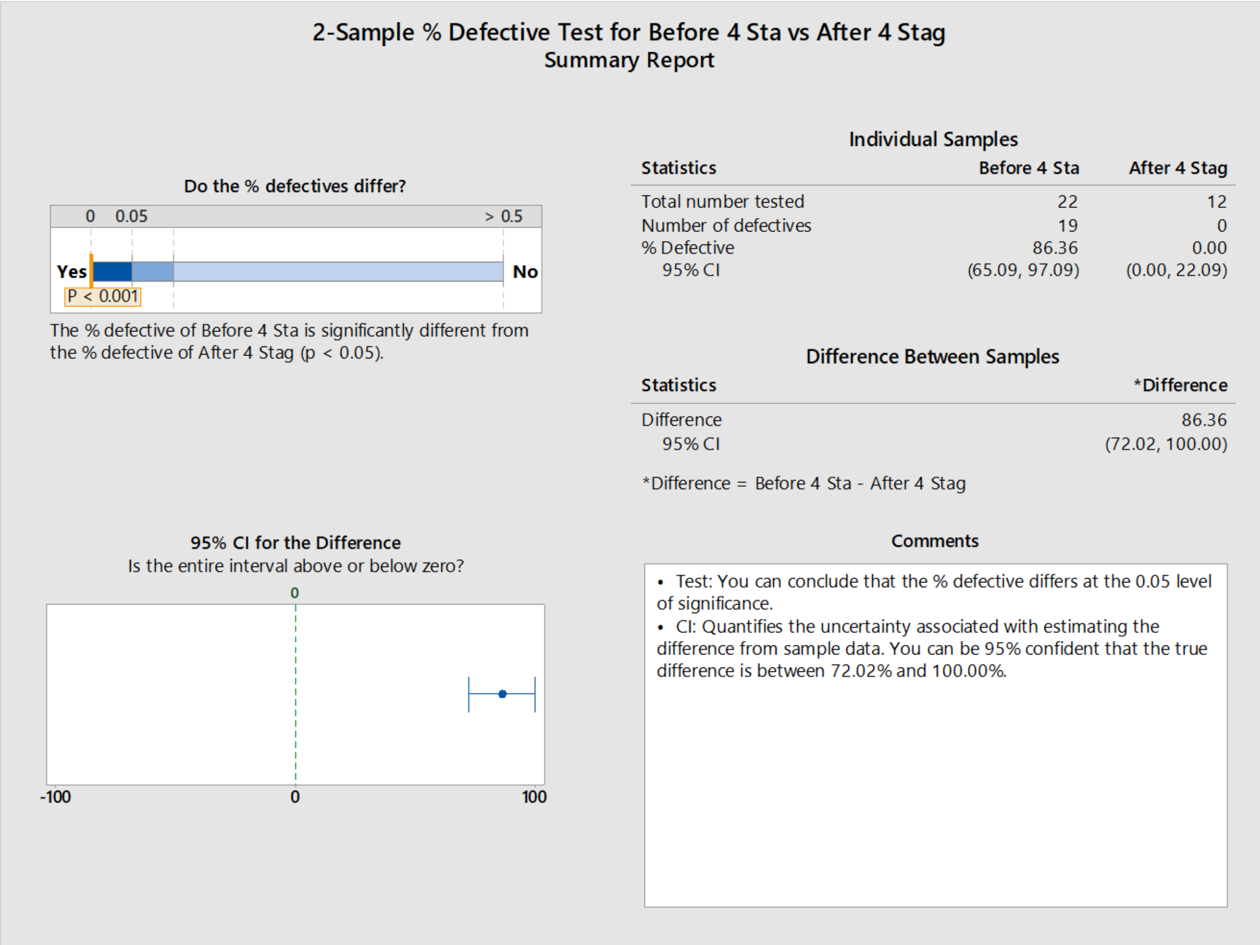


Figure 48: The 2P hypothesis test for Case Study 1

The P-value was less < 0.001 which is than the decision cut off point of < 0.05 so the Null hypothesis was rejected.

5.3 Case Study 2: DMM

5.3.1 Introduction to the company

Founded in 1981 as Moorhouse Engineering in Bethesda, the name of the company was changed DMM and moved to Llanberis in 1986. The company has developed products in two main areas; Recreational Climbing and Mountaineering has developed alongside products aimed at the Industrial markets. DMM has a full production, machining and assembly process and it is the only facility of its type in the UK.

5.3.2 The raw data

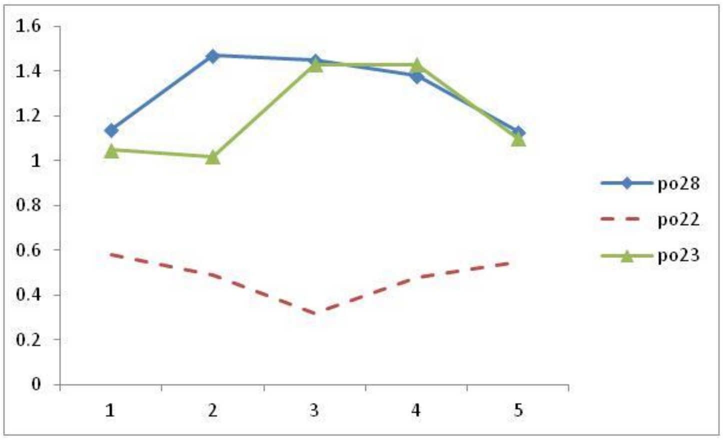
This section provides a summary from the raw data collected from DMM, the questionnaire has been used in the data collection process. The questionnaire was shown in Appendix 3.

Product problem – detailed process	Data collection
1. 	Within DMM, there are five Hare 25-ton hydraulic presses on the shop floor, of which, three are used for clipping; clipping is a term used for removing excess waste from aluminium forgings. Prior to using the framework in this research, a Cause and Effect diagram had been completed. The initial thought was that the variation seen was due to the ability of the operators to operate the press.
2. (Yes – go to step 3, No – go to step 4)	The production target was to produce 10 batches of karabiners using the three clipping presses in a 7 ½ hour shift.

Is the target known?	
3. How far from the target is the problem?	How - Some batches are clipped in under an hour, some take longer.
4. Collect facts to answer the following questions:- The 2 H questions What product has the problem? Where on the product is the problem? Where in the process is the problem seen? Who found the problem? When is the problem seen? (Trends)	Who – The problem was seen following monitoring operation times on factory data capture system. What – All Karabiners had the same problem dependent on which press was used. Where in the process - During the clipping operation?' the process was shown below. The batches are completed quicker on press PO22 than on PO23 or PO28. Only some of the variation can be explained by the operator to operator effect, the biggest variation shown is between the presses. Further observation of ram travel time on the presses showed that PO22's ram was faster than PO28 or PO23; this led to an investigation of the various parts of the press which could slow down the ram speed. (The ram function is described in the next section)

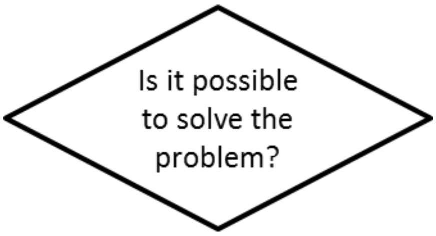
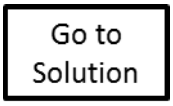
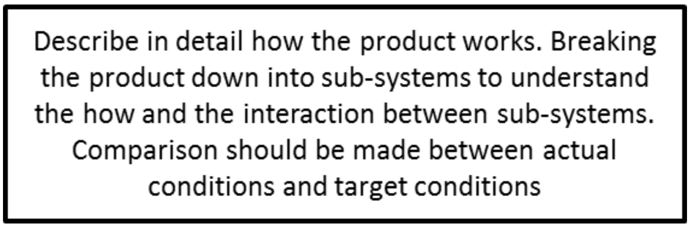
<table>
<tr><td></td><td>Where on the product - There was no problem regarding the product.

When – Press to Press differences had been present for a long time. The trend was a lot of variation in timings from press to press.</td></tr>
<tr><td colspan="2">

The process map


Y axis – time (hours)
X axis – 5 different batches
The batch time by Press</td></tr>
<tr><td>5.

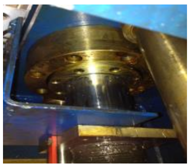
Based on the facts write a problem statement</td><td>When monitoring the data from the Hare HP 25 ton clipping process for all karabiner types, a deviation was seen between the presses which could not be explained by different operators, observation of the ram travel time showed a difference</td></tr>
</table>

<table>
<tr><td></td><td>between the PO22 press and PO28 or PO23 presses.</td></tr>
<tr><td>6. (Yes – go to step 7, No – go to step 8)

<table>
<tr><td>W1</td><td>W1</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>W2</td><td></td><td>W2</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>W3</td><td></td><td></td><td>W3</td><td></td><td></td><td></td><td></td></tr>
<tr><td>W4</td><td></td><td></td><td></td><td>W4</td><td></td><td></td><td></td></tr>
<tr><td>W5</td><td></td><td></td><td></td><td></td><td>W5</td><td></td><td></td></tr>
<tr><td>W6</td><td></td><td></td><td></td><td></td><td></td><td>W6</td><td></td></tr>
<tr><td>H1</td><td></td><td></td><td></td><td></td><td></td><td></td><td>H1</td></tr>
<tr><td>H2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table></td>
<td>It was not possible to solve the problem. The decision matrix is shown below.
<table>
<tr><td>W1</td><td>W1</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>W2</td><td>x</td><td>W2</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>W3</td><td>x</td><td>x</td><td>W3</td><td></td><td></td><td></td><td></td></tr>
<tr><td>W4</td><td>x</td><td>x</td><td>x</td><td>W4</td><td></td><td></td><td></td></tr>
<tr><td>W5</td><td>x</td><td>x</td><td>x</td><td>x</td><td>W5</td><td></td><td></td></tr>
<tr><td>W6</td><td>x</td><td>x</td><td>x</td><td>x</td><td>x</td><td>W6</td><td></td></tr>
<tr><td>H1</td><td>x</td><td></td><td>x</td><td>x</td><td>x</td><td>x</td><td>H1</td></tr>
<tr><td>H2</td><td>x</td><td></td><td>x</td><td>x</td><td>x</td><td>x</td><td></td></tr>
</table></td></tr>
<tr><td>7. (Implement and collect data to prove the solution)
</td><td></td></tr>
<tr><td>8.
</td><td>The presses are Hare HP 25-ton hydraulic presses. Figure 45 shows the workings of the clipping process.</td></tr>
</table>

Hare HP 25 ton clipping press

Ram support valve

Once the press is switched on the motor and hydraulic pump are activated, oil is then pumped up through narrow pipes to an electrically-operated valve block (ram support valve)

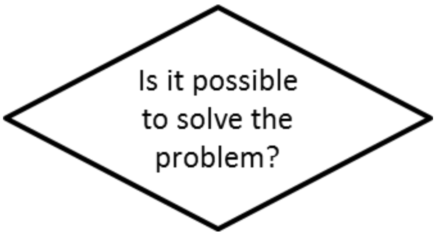


Hydraulic ram

This is operated by a PLC module to open and close, as the valve is opened oil is sent through at high pressure to the hydraulic ram, where oil pressure forces the ram down, as the ram reaches the bottom of its stroke the PLC module opens the dump valve to re-direct the oil back to the tank returning the ram to its starting position, completing the cycle of the press.

Stage 2 - How does it work?

9. (Yes – go to step 10, No – go to step 11)

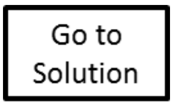


W1	W1						
W2		W2					
W3			W3				
W4				W4			
W5					W5		
W6						W6	
H1							H1
H2							

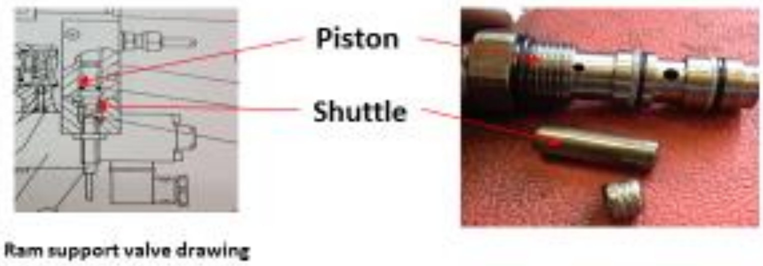
Following this stage, the root cause of the problem was discovered by observation, and the solution implemented. The decision matrix is complete following Stage 1 and 2.

W1	W1						
W2	x	W2					
W3	x	x	W3				
W4	x	x	x	W4			
W5	x	x	x	x	W5		
W6	x	x	x	x	x	W6	
H1	x	x	x	x	x	x	H1
H2	x	x	x	x	x	x	x

10. (Implement and collect data to prove the solution)



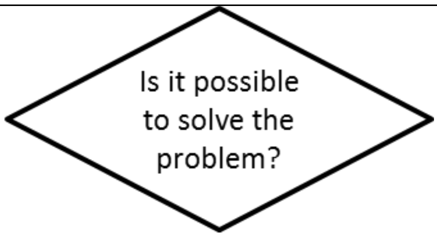
On inspection the ram seals and light guards were found to be in good order, this left the ram support valve to be the likely cause. Within section 10 the investigation and solution are given. As part of the solution, the valve that was at fault was swapped from one press to the other and the problem moved

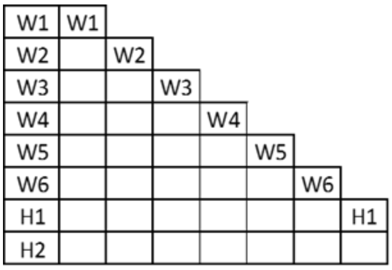
<table>
<tr><td></td><td>from one press to the other. Thus, proving the solution. The benefits of this project were a reduction in clipping times from 1:31 minutes to 0:51 minutes. This provided an extra capacity to clip of 52000 karabiners each month.</td></tr>
<tr><td colspan="2">

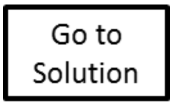
On closer examination of the old valve I found that the shuttle housing inside the piston had broken, this would cause the shuttle to stick reducing oil flow to the ram and slowing the press down.

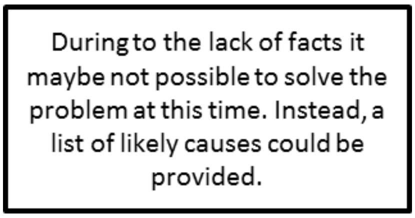
The Solution</td></tr>
<tr><td>11.

A series of experiments needs to be proposed to collect further data to obtain the missing facts?</td><td></td></tr>
<tr><td>12. (Yes – go to step 13, No – go to step 14)</td><td></td></tr>
</table>

<table>
<tr><td>




</td><td></td></tr>
<tr><td>
13. (Implement and collect data to prove the solution)


</td><td></td></tr>
<tr><td>
14.


</td><td></td></tr>
</table>

5.3.3 The measurement of improvement and validation of the outcome

The DPMO metric and the hypothesis test are both trivial as the before was 100% and the after is 0%. The problem was completely understood and solved, and the perceived initial root cause, operators, was incorrect.

5.4 Analysis of the Case Studies

To provide a measure to the benefit from using the process. Table 15, has been prepared for each case study, using before and after data.

Case Study	Before	After using Framework
1	\$80K loss per week 19 rejects per 22 produced Rework costs Production delays	No loss \$ 0 rejects No rework No production delay
2	Targets not achieved Operators get blamed Bottleneck process	Problem solved Root cause not operators Bottleneck moved Potential extra 52000 units per month

Table 15: Before and After results (Case studies)

The use of SPC was shown in the Flow Products Limited case study and shows the pattern of data points below the original mean follows the rule defined in the research method, seven points above or below the mean. Therefore, this indicates a process change. This was further supported by the cumulative average plots; this plot is not meaningful for the DMM case study as the problem was completely removed from the process.

Both the case studies have large pre-framework DPMO figures, Flow Products Ltd 863636 ppm and DMM 1000000 ppm and the post framework figures are 0ppm. Therefore, the hypothesis testing using the 2 P test support the rejection of the null hypothesis in both case studies.

5.5 Stories using the framework in Chapter 4

This section details supporting evidence for the 2 case studies. The initial development of the quality problem-solving framework was undertaken from 2009 to 2012. During this period, the concept was developed and tested in a several different business sectors. To demonstrate the benefit of the concept a narrative of four examples with the outcomes of the implementation of the concept are provided. To justify the narrow lens approach, the analogy of Taylorism is used. The management theory (wide lens) was presented in the book, 'The Principles of Scientific Management' published in 1911, yet the data collection started during the 1880's with single observations (narrow lens).

5.5.1 Problem 1 – Automotive Industry

Background - Company X was a multinational automotive manufacturer that supplies automotive components worldwide. The problem experienced by several customers was centred in North America. When the problem occurred, it resulted in a sealed component blowing open, and the customer hearing a loud noise from the area of the engine. Thus, the vehicle automatically stopped working. Typically, the failure occurred after low to mid mileage. Several failures resulted in the customers contacting the dealer from whom they purchased the vehicle. Consequently, the dealer contacted the Original Equipment Manufacturer (OEM) who then initiated a Root Cause Analysis investigation within the supply chain. It was at this point; the author became involved in the investigation. The total number of vehicles under investigation was 835. The author was involved in identifying patterns and common themes. At the time of this investigation, the 8D method was being deployed. The supplier of the faulty component had brainstormed possible root causes and had produce a list of 46.

How – A sealed component blowing open, and the customer hearing a loud noise from the area of the engine

When - 10 vehicles from the population of 835 had failed. The failed 10 components were seen to be randomly spread throughout the 835 vehicles. The failure was seen in a random pattern but early in the vehicle's life.

Where on the product - The component had been analysed, and all had the same failure mode. The failure was seen in the same position on each component.

Where in the process - A detailed process map was produced, from the point of failure. During this process, a problem was seen with the pipe work connectors to the component in the OEM. Put simply, the inlet and outlet connectors from the vehicle subsystem to the failed component could be mixed up.

Who - The assembly of each component from the tier 1 supplier was traced, which revealed no pattern, that is, not all assembled by the same operator. Further analysis was undertaken by fixing the inlet and outlet pipes incorrectly, and the failure did occur as seen in the field.

The solution - A poke yoke solution was implemented to make it impossible to mix up the inlet and outlet pipes during assembly. Proof that the action had worked was seen in the next 1024 vehicles for which no further problems were observed, at which point monitoring was stopped. The liability was in the region of $10000 per vehicle, this figure was not paid by the supplier who solved the problem.

5.5.2 Problem 2 Automotive Industry

Background - Components were produced in large quantities and tested for leakage rate. The components formed part of the cooling system on a vehicle

How - The components had a leakage rate which was above the specification.

Who and When - The problem was seen on all shift patterns and the inspector, working at the automatic leak testing inspection process, reported the problem.

Where on the product - The leakage on the component was seen in a random pattern at either the top or bottom of the component.

Where in the process - The study of the process revealed that the production of the part, the part evacuation and the positioning in the dryer furnace, all process steps prior to testing, could only be undertaken in one way.

Further data collection - The only process where the variation could be introduced was in the manual part transport to the dryer. Further experiments on the process revealed that holding the part in several different angles during manual transport resulted in a high leakage rate. Only holding in the vertical position was acceptable.

Solution – The operators were trained to ensure the transportation was undertaken in the correct manner.

5.5.3 Problem 3 – Construction industry

Background - Sections of a product used in the construction industry failed to meet the specification resulting in scrap product. As the product was produced, the initial section of the product was monitored and removed from the process line. The problem is known and therefore the initial section of product was always removed.

How – High level of scrap. The problem became greater the longer, the process was switched off and a whole section of the product was outside the specification and deemed scrap.

Where on the product - This problem affects all products that used the process.

Who - The problem was independent of the shift or operators on the process.

When - The problem occurred when the process has been switched off and restarted.

Where in the process - It was discovered that the raw material recirculation pipe work did not include a section of pipe prior to the production process. Therefore, material in this section was not recirculated and therefore deteriorated over time. Once the line was restarted the material in that section of pipe work produced a length of defect product.

Solution - The problem was reduced once the recirculation pipe work was extended nearer to the production point.

5.5.4 Problem 4 Automotive Industry

Background - This problem concerned the level of rework in a production process. In this problem, one in three components required reworking due to leakage.

How – A component leakage

When - The leakage occurred across all shifts and at the rate of 1 in 3 components produced.

Where in the process - The deviation was seen at a testing station. One process involved stacking several components for a treatment, the components were stacked in three positions. The position of the leakage on the component was random across the assembly at the interface of two sub-components.

Further data collection - Due to the timescale, a structure was created to determine further actions for the collection of facts. The structure used was the WWBLA structure given in stage 2 of the initial concept. This was given as in Figure 49.

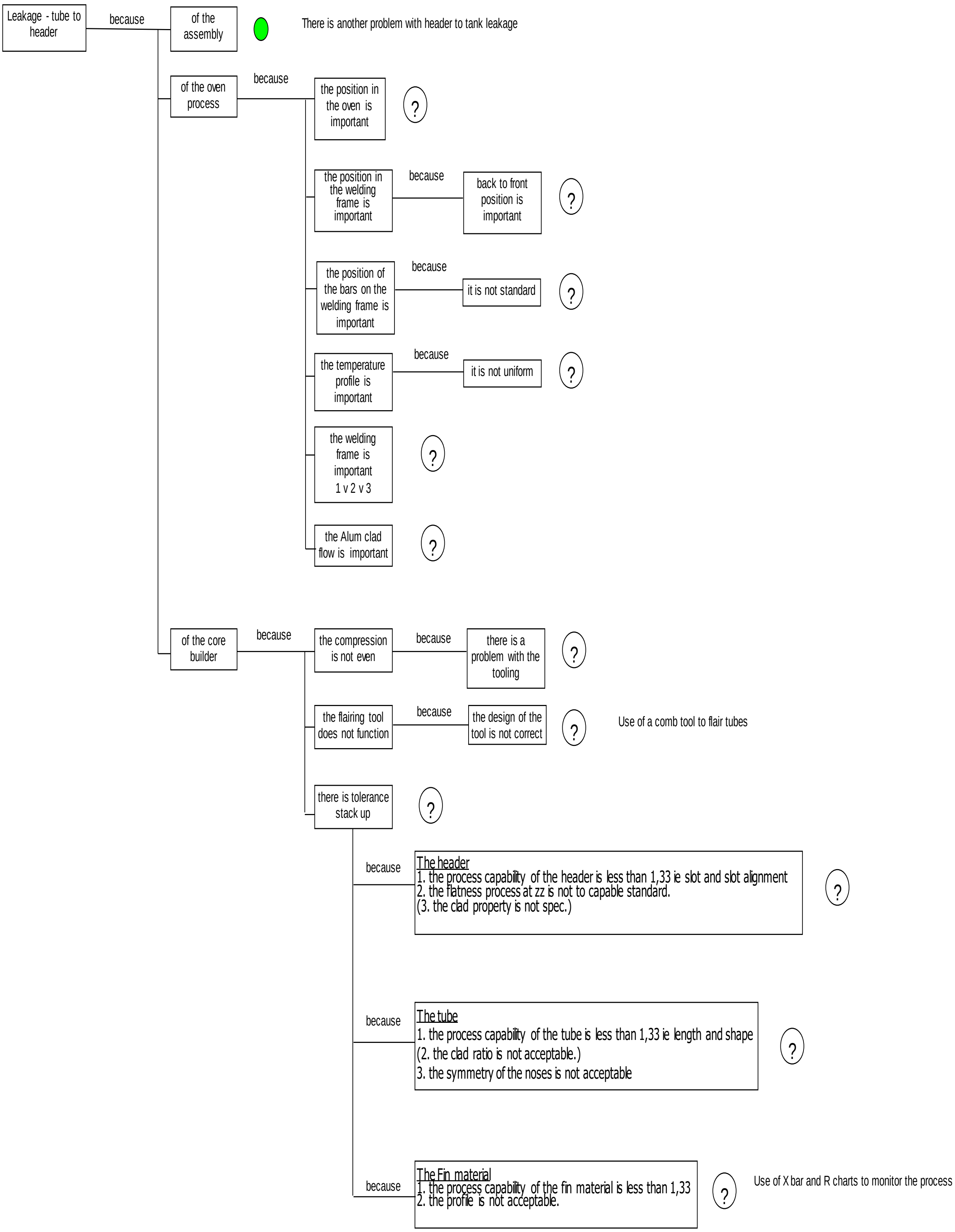


Figure 49: Structure for Story 4

One action was to review the process in which the components were stacked in three rows and processed in vacuum conditions. However, the vacuum motors were making a non-standard noise. On further investigation, the motor for the top section of this process was found to be working incorrectly but it was not recorded on the instrumentation.

Solution - Once repaired, the level of component rework was reduced to standard levels in the low single figures, which was to be expected of this type of production process.

5.5.5 Analysis of Problems 1 to 4

Problem 1 shows that the traditional automotive problem solving 8D method resulted in the user developing a long list of actions. The initial brainstorming session resulted in a potential 46 root causes and did not include the actual root cause. Once the facts were reviewed and the whole process considered from supplier to end users, a gap in the facts revealed the root cause of the problem. Problem 2 in the detailed study of the process and the method used by the different operators on the production line, revealed a variation in the method of part transport. Problem 3 is like the previous problems, in that the process review and how the process was intended to operate, revealed the issue and the root cause of the problem. Problem 4 had a high reject rate and the use of Global 8D, had failed to determine the root cause of the problem, but had led to additional rework stations being placed in the production line. By providing a fact-based action plan to fill the gaps in the knowledge proved invaluable and the root cause of the problem was found and fixed. Table 16 has been prepared for each problem using before and after data.

Problem	Before	After
1	10 in 835 units rejected $100,000 potential loss	0 in 1024 units Actual loss $0
2	20% leakage rate	0 issues
3	5 metres reject for each line stop	< 0.5 metres per each line stop
4	33% reject Special shipping to the customer	0% reject

Table 16: Before and After results (Stories)

5.5.6 Summary from the Stories

The stories presented satisfy the description of a story as given by Moezzi et al (2017), that was a start, middle and end. These stories are presented to provide further evidence of the use of the framework given in Chapter 4 and allow for a statistical analysis which was presented in Chapter 5.

5.6 Summary of the Chapter

Within this chapter the process, proposed in Chapter 4, had been used to solve two quality problems from different companies, Flow Products and DMM. By working on the quality problems with the companies it has been possible to evaluate the framework and detailed process and its effectiveness has been demonstrated. In both cases, an initially unknown quality problem has been solved. The benefits to the companies have also been measured. In both cases, an initial high level of non-compliance has been removed, in the DMM case study the problem has been completely removed from the business. As only two case studies have been given, a formal statistical analysis with respect to the research process was not relevant, therefore, the research has a bias. However, it was possible to provide a practical demonstration of the process, it was possible to demonstrate how the framework and detailed process provides a contribution in the field of quality problem-solving. An important element of this chapter was the discussion and rationale as to how the research questions have been answered. The literature review analysis results in several findings and therefore, research gaps, as shown in Figure 5 (Chapter 2). These include: -

- No linkage between quality definitions and quality problem-solving frameworks
- The use of tools/techniques used within a framework which encourage the collection of opinions and guesses

These research gaps have driven the research and the establishment of the framework and detailed process given in Chapter 4 was the result. At this point in the research, the proposed framework was theoretical in nature. To test the theory, a research method, Chapter 3, was developed. This method has allowed the framework and detailed process to be tested in real world situations by using case studies. The use of case studies required ethical approval from the university. The results of the application are given in this chapter, Chapter 5. The outcome was positive for the two case studies presented. Therefore, the contribution to knowledge was not only theoretical but practical. The conceptual model to test the effectiveness of any quality problem-solving frameworks was also used during the research. The conceptual model was used to address the question of using any other frameworks to solve the same quality problem. It was not possible to compare the different frameworks with the same quality problem, as once a quality problem was solved, prior knowledge overrides the use of any other frameworks. This also could provide an explanation as to why no conceptual models to compare the efficiency of quality problem-solving frameworks exist in current literature. However, a situation does exist where another framework can be used if the quality problem was unsolved following the use of an initial framework. This case was presented within the chapter 4, the first case study used the framework of Global 8D initially, but it was the 5W&1H conceptual model which solved the quality problem.

To test the validity of research, the standard approach was to use statistical hypothesis testing, this would involve data collection of a suitable sample size and then the application of an appropriate test. Within this research, it has been possible to test the individual case studies as the before and after, use of the detailed process, data has been collected. Both problems were solved, and the hypothesis test was statistical significant in support of the use of the framework. The bigger question as to the effectiveness of the framework, was unanswered in this research, this is a topic for future research; this would require a statistically valid sample of quality problems across a range of businesses. The quality problems would need to be unsolved prior to using the framework. Furthermore, the testing of the framework, in a service sector problem, has not been undertaken in this research.

The research has now provided evidence to support the initial thoughts prior to the research being undertaken. These initial thoughts were driven by an interest in the field of quality and quality problem solving frameworks. Having learnt and applied the frameworks given in Chapter 2 in a practical business setting, there was a belief that a research gap existed within these fields, therefore, the research gaps. However, the subject matter of quality was established, as are the frameworks to solve quality problems. Therefore, the establishment of research gaps would require in depth research and a deep knowledge of the subject. The need to learn suitable research methods and approaches was vital to establish research opportunities within established topics. The understanding of how to conduct such research has been gained during the research period. This knowledge has been applied in detail to demonstrate that a gap did exist. The content of Chapter 3, the Research Method, was a result of extensive research into the use and application of research methods used in research to a PhD standard. The content of Chapter 4 and 5 and was based on author’s prior knowledge into the research topic and the learning during the period of this research. The main contribution to knowledge can be summarized as the practical demonstration of a quality problem-solving framework which addresses gaps seen in the research of this subject matter.

CHAPTER 6

DISCUSSION

This chapter provides a discussion on this research. The thesis has examined the fields of quality improvement techniques used in the production of products. The timeframe considered was the 20th Century to the present. It is possible to split the timeframe into a number of events which have shaped the research field. These include the development of the PDCA/PDSA approach which proposed by Shewhart, in the early 20th century, which has been developed into the Kaizen approach widely used today. Another development was the Six Sigma framework by Motorola in the late 20th Century. Garvin (1987) and Chase and Aquilano (1989) assessment of the research field undertaken prior the widespread acceptance of Six Sigma, concluded a lack of a problem-solving structure linked directly to the definition of quality. Research to determine more timely and current references was fruitless. Six Sigma does provide a clear target for the quality outcome for any process, that was 3.4ppm. Prior to this quality was not tangible and difficult to measure due to differing views of quality, this was discussed in Chapter 2. However, the next stage was to link the definitions of quality and quality problem-solving techniques. By doing so, the question can be addressed which are, what is quality? and what is the framework to achieve quality? This research would suggest that the quality problem solving techniques have been developed independently of how quality was defined. De Mast (2013) concluded that research which, 'studies of how experienced and successful problem solvers work, may enrich the theory about diagnostic problem solving' (De Mast 2013). De Mast does not propose a method or approach to enrich the theory of diagnostic problem solving. The analysis presented by De Mast includes Six Sigma and Shainin. This research has developed and demonstrated to application of a diagnostic problem-solving framework in the context of quality problems. The framework was the structure to follow from the problem to the solution, the process steps, the next step was to consider the tools and techniques used within the frameworks. A major finding was that the use of the why question is wide spread in quality problem solving techniques. This was despite of references through the 20th Century that suggest that asking why during problem solving can be misleading. The Kipling Model may provide evidence for the use of the why question, as the model was developed in early 20th Century. Using this definition, allows an organisation to highlight problems and then provides a framework to address the problems. The weakness of the why question was an issue, highlighted by Browne & Keeley (2004), Rademeyer et al (2009), Ayad (2010) and Minoura (2011). This research has recognised the weakness of the why question and removed the opportunities to ask the why question from the framework.

This section of the chapter provides a discussion for the justification for the quality problem solving conceptual model/framework/detailed process given in Chapter 4. The justification was needed to clarify the contribution to knowledge. The analysis, in Chapter 2, suggested no established linkage between the definition of quality and frameworks to solve quality problems. The research does highlight the Six Sigma framework; which does provide a target for quality, 3.4ppm, and a framework, DMAIC to structure quality problem solving, but the two are not linked in a formal manner. The lack of linkage between the definition of quality and a framework to achieve the level of quality, was important within this research. By providing a clear link, the detailed process given in Chapter 4 was developed. The detailed process uses the definition of quality, on target with minimum variation, to drive the quality problem-solving framework through to a solution. This approach of a linear process rather than a circular process was considered important to achieving the solution. To further enhance the contribution and to provide a context for all quality problem-solving frameworks, a conceptual model was given in Chapter 4. Using the conceptual model, it was not possible to test frameworks against each other using the same quality problem, as it was only possible to solve a quality problem once with the same group of participants. With respect to the conceptual model, the dominant factor would be prior knowledge if the solution was known to the group independent of the chosen quality problem-solving framework. Figure 50 provides a representation of the conceptual model in which the solution to the problem was known. This was highlighted in Chapter 4 and was the reason why the conceptual model is required.

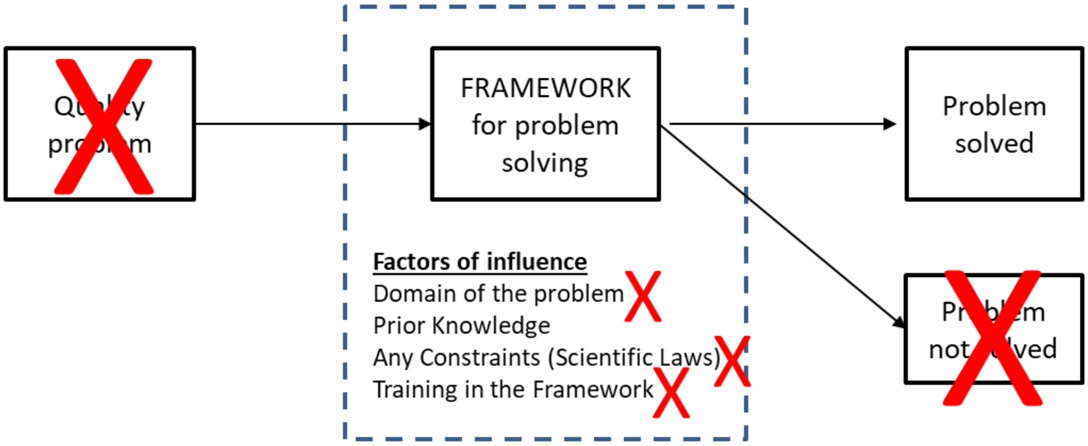


Figure 50 Breakdown of the conceptual model with prior knowledge

The inability to be able to test the hypothesis to compare frameworks with the same quality problem could be considered a research weakness. However, any conceptual model proposed to research this subject would also have this weakness. This was a possible explanation of the reason why there was no conceptual model found in the literature review, this point was raised earlier in Chapter 4. The conceptual model provides the components of quality problem-solving and any framework for quality problem-solving can be tested with this model. In Table 15, potential issues for each component which could occur when testing a quality problem-solving framework was given. Having considered the potential issues, a column of the table details how the proposed framework in Chapter 4 has addressed the issues.

In Chapter 3, the research method, has been designed to test the effectiveness of the framework once it was applied in the primary data collection phase.

Component of the conceptual model	Potential Issues	How the proposed framework addresses these issues
Prior knowledge	No prior knowledge of the problem could be useful. But it is only useful if brainstorming is not used as this encourages the collection of opinions and guesses and will be shaped by prior knowledge.	In Stage 1 of the framework the collection of the facts is critical. This is demonstrated within the case studies.
Domain & Constraints	These are considered jointly as lack of domain knowledge and/or constraints knowledge within a framework could result in a problem being unsolved.	In Stage 2 of the framework, the user is expected to explain 'How it works?' in doing so the user will understand the domain and constraints to the quality problem to be solved. This was demonstrated within the case studies and for the DMM case study it was the stage where the problem is solved.
Training in the framework	Without user training in the application of the framework for quality problem solving is not possible to use it.	For both the case studies user training was given prior to use of the framework and the process.

Table 17 Potential issues with the conceptual model

Table 17 demonstrates how the proposed framework has been used to overcome the issues with testing quality problem-solving frameworks. Therefore, the outcome of the case studies was positive, and the results are measurable. A further component of the framework was no solution to the problem, given in the conceptual model as 'problem not solved'. Then, it was possible to use another framework to try to solve the quality problem. However, the risk with such an approach was that the level of prior knowledge could become a dominant factor. To counter this risk, if the other frameworks encourages the user to collect opinions and guesses, then the prior knowledge could be misleading. From the analysis, in Chapter 2, it was possible to argue that the use of opinions and guesses was prevalent within all tools/techniques. One indicator of this behaviour within the quality problem-solving process, could be large numbers of possible root causes determined during brainstorming the quality problem. There was evidence of this behaviour within this research, prior to using the proposed framework, users in the DMM case study, used a brainstorming session to collect ideas as to the root cause of the problem. This resulted in 11 possible causes. The root cause, which was determined by using the proposed framework was included in the list. Therefore, the brainstorming approach being used would have resulted in an investigation of up to 11 possible root causes. However, the case study presented in this chapter using the detailed process, given in Chapter 4, did determine the correct root cause without the need for any opinions, guesses and asking why which the prior work into this problem had used, but significantly, the problem had not been solved.

The use of case studies to justify the research approach was given in Chapter 3. As the author, has intentionally selected theoretically useful case studies the use of statistical hypothesis testing would be considered biased. Furthermore, the use of hypothesis testing with a sample size of two was possible but not meaningful, when testing the hypothesis; does the proposed framework provide a positive outcome in the solving of quality problems?

The answer to the hypothesis was binary i.e. yes or no. The correct hypothesis test would be a two-proportion test (2P test). However, by using the concept of power and sample size with respect to the 2P test, it was possible to determine a minimum number of case studies required to achieve a meaningful hypothesis test result. The number of examples of using the framework was a minimum of six, in which five would need to support the use of the proposed framework. Within this research, 4 ‘stories’ and 2 case studies within this chapter all support the use of the framework given in Chapter 4. Figure 51 provides the analysis.

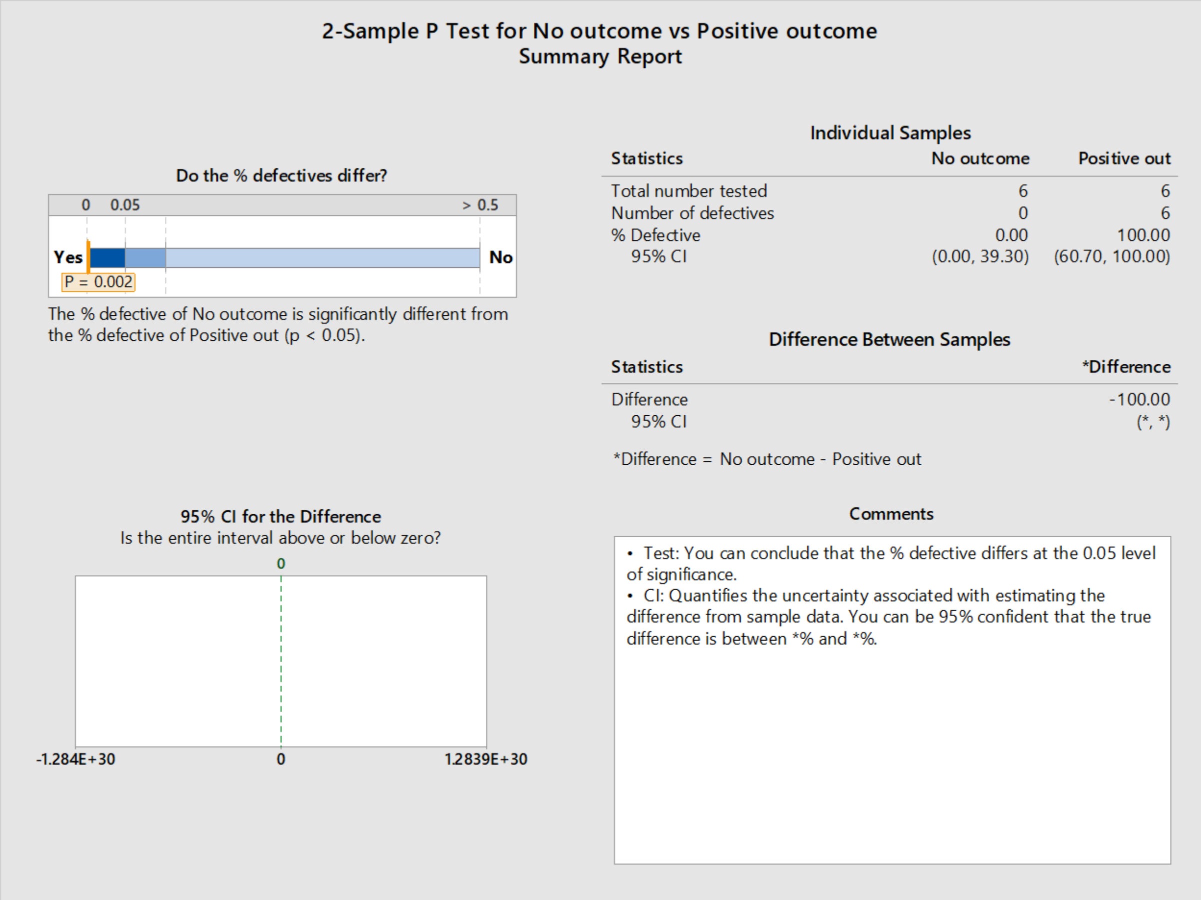


Figure 51: The 2P Hypothesis test (Minitab)

However, in adopting such a research approach, it would still be possible to argue that, intentionally selected theoretically useful case studies to support the research hypothesis had been selected. Therefore, a research bias would still exist. One possible way to address this issue of bias was to conduct a large research project across a range of domains and quality problems. Such a project would require significant resource and was considered as a potential future opportunity for the application of this research. This research has obtained ethical approval for a primary data study, to this end two case studies and 4 stories have been used to demonstrate the framework and detailed process.

CHAPTER 7

CONCLUSION

This chapter provides a conclusion to this research. Following this, the author has provided a discussion on research limitations, personal reflections following the research process and potential further research.

This thesis has examined the area of quality and quality improvement techniques since the 1920's. The conclusions from the introduction, following an overview of the area of research, were as follows. The initial assessment would indicate that there are several different definitions of quality, and that these are clear, but the lack of a framework linked to the definition does not allow the definition to have any leverage in a business context. Prior to the development of Six Sigma, quality was not tangible and difficult to measure. Six Sigma provides a clear definition of quality and therefore, it was tangible. However, the next stage was to link the definitions of quality and quality problem-solving techniques. By doing so, the question can be addressed which are, what is quality? and what is the framework to achieve quality? This research would suggest that the quality problem solving techniques have been developed independently of how quality was defined. A major finding was that the use of the why question is wide spread in quality problem solving techniques. This was despite of references through the 20th Century that suggest that asking why during problem solving can be misleading. The Kipling Model may provide evidence for the use of the why question, as the model was developed in early 20th Century. Because of the initial research of quality and the techniques recommended to solve quality problems, research questions have been proposed which provide a starting point for the literature review in chapter 2.

This research has addressed the question raised by Garvin (1987) and Chase and Aquilano (1989) who have identified various gaps in the approaches to quality. These include the absences of a clear, conceptual framework and a 'sound instructional methodology' to help an organisation study quality and which aspects of quality matter, how much is required, and how to determine customer needs sufficiently. This was presented in Chapter 4. Although, these assessments given are based on the 1980's there was no further evidence found within the literature to fully support that these absences have been addressed. Therefore, this research provides evidence to address this gap identified in the 1980's. Another research gap was a conceptual model to compare different quality problem solving frameworks. The literature review revealed the existence of no conceptual model. To address this research gap, a model was developed and has been presented in Chapter 4 and with discussion in Chapter 5. The reason for no conceptual model was trivial, as prior knowledge makes the solving of a problem twice impossible. A common theme with the framework was the use of the why question. The potential weakness of the 'why' question was highlighted by Browne & Keeley (2004), Rademeyer et al (2009), Ayad (2010) and Minoura (2011). To address this weakness, the framework presented in Chapter 4 will not use the 'why' question. The research into frameworks undertaken by De Mast (2013) detailed in the literature review provides a comprehensive review of the state of quality problem solving frameworks, which further supports the data presented in Table 7. Therefore, any new framework should address the gap detailed by De Mast (2013). The main outcome was the enrichment of the theory about diagnostic problem solving achieved by the study of how experienced and successful problem solvers work. This research provides a solution to this challenge proposed by De Mast. Chapter 4 details the contribution to knowledge within this research. The outcome of the literature review was an assessment which highlighted the research gap. That was, that techniques which allow the user to include opinion and guesses, by using the why question, in the problem definition process, can result in solvable problems remaining unsolved. To develop this research opportunity further, several examples of quality problems have been presented and a justification for the examples was also provided. These problems have been solved using a fact only based approach during this research timescale. From these problems, a conceptual model, a framework and detailed process for production and service problems, this then addresses the research gaps. The development of the solution was described in detail; it follows a process from an initial conceptual model through to a full detailed step by step process. To support the development from conceptual model to detail process flow, a literature review was included using suitable and appropriate references. The development includes a comparison between a paper published in 2012, during the time of this research and the findings of the examples given in the literature review. This comparison was then further developed with an analysis of current techniques and a rationale for the use of defining a problem as the level of deviation from target. Having completed this analysis, it was possible to define the step by step process flow, which was the contribution to knowledge. To enhance the framework from problem solving only, to a complete process, the topic of solutions was discussed and included and added to the process. This was the authors full contribution to knowledge.

During the research, it has been possible to provide answers to the research gaps given in this research. In doing so, the following contributions to knowledge are given:

- The conceptual model for comparing problem solving frameworks.
- Providing further research into the use and consequences of asking the why question during problem solving.
- Proposing a framework and detailed process flow for problem solving based on establishing a relationship between the definitions of quality and a problem-solving framework/detailed process. In this research the definition of quality is ‘on target with minimum variation’ and the framework/detailed process from problem to solution is given in Chapter 4.

- The framework/detailed process has been proven using two unique case studies from two different business sectors.

With all research, there are limitations. Bias is a major weakness in any research and impossible to eliminate. To mitigate bias that can affect the validity and reliability of the results, several actions have been taken: first, different methods have been used to collect the data including direct observations for the case studies; second, the author has provided the full script of the data collected, which has been recorded and analysed. The 5W&1H conceptual element of the model within this research has also been published in a recognised journal. This research has not set out to test the reliability and validity of the conceptual model and framework. This was a limitation on which further research is required.

A personal reflection on conducting research, research was long and slow in development and therefore, challenging. Learning the research process was rewarding, how to ask the searching questions, the development of writing skills, the development of communication skills, the development of conceptual models and how to reference in the correct manner are useful skills for any subject matter. Knowledge is only obtained with a well-developed research method, and contribution to knowledge requires both knowledge of subject matter and a research method.

The areas of potential future work could include:

- Further application of the method across a wider range of business sectors, including the service sector, and more general problem solving with respect to other disciplines, for example medical, social and economics.
- Development of the fact-based questions tailored to suit different business sectors. For example, are there fixed questions which should always be asked in certain situations?

- To test the reliability of the conceptual model and the framework/detailed process given in Chapter 4 with a larger sample of problems including unsolved problems following the use of other problem-solving frameworks.
- To understand the link between the tools and techniques with respect to the history of this topic. The point raised in Chapter 4 about brainstorming, it was important to remember this topic was developed within a business context and not an academic environmental, therefore, the research findings may not match those expected in the lather context.

PhD research will stand the test of time and/or provide a significant input into the next contribution to knowledge. The research requires the author to demonstrate an in-depth knowledge of the research topic. Prior knowledge of the topic is, of course, useful, but it can also, blinker the research process. The knowledge gained during the research method learning as part of the PhD process was vital to ensure the research topic was fully explored, the data collection was representative of the research topic, the research gap was real and can be written as a research hypothesis, the proposed contribution to knowledge can bridge the gap, it was possible to detail the contribution so other researchers can follow and use the contribution, the author was able to demonstrate the application of the contribution with data, was able to analysis the data collected during the research and provide appropriate statistical analysis to prove or dis-prove the research hypothesis, draw conclusions and recommendations for future research, and finally realise the boundaries and limitations of the contribution to knowledge.

References

Ali Ahmadi A (2007) "A comprehensive review of strategic management", 5th edition, Tolid-e-Danesh

MR Alfian (2013) The Impact of Globalization Process of Hip-Hop Music in Semarang as a Reflection of American Pop Culture (A Case Study of Semarang Hip-Hop Community) Journal on English Language and Culture - ejournal-s1.undip.ac.id

Altrichter, H., Kemmis, S., McTaggart, R., & Zuber-Skerritt, O. (2002). The concept of action research. The Learning Organisation. 9(3), 125–131; republished in Volume II of Cooke, B., & Cox, J. W. (Eds.), Fundamentals of action research (pp. 101–113). London: Sage Publications.

Altshuller, G., (1996). And Suddenly the Inventor Appeared. Technical Innovation Centre, Worcester, Massachusetts., Originally published in Russian 1984.

Altshuller, G., (1999). The Innovation Algorithm: TRIZ, systematic innovation, and Technical Creativity. Technical Innovation Centre, originally published in Russian 1969 and 1973, Worcester, Massachusetts.

American Society for Quality, Glossary – Entry: Quality, retrieved 22 05 2017

Argyris, C., & Scho¨ n, D. A. (2005). Participatory action research and action science compared: A commentary. American Behavioral Scientist. 32(5), 612–623; republished in Volume II of Cooke, B., & Cox, J. W. (Eds.), Fundamentals of action research (pp. 137– 147). London: Sage Publications.

Awasthy, D., Banerjee, A. and Banerjee, B. (2012), "Understanding the Role of Prior Product

Ayad, A. (2010) Critical thinking and business process improvement. The Journal of Management Development 2010;29(6): pp 556-564

Barry, K., Domb, E., Slocum, M.S., (2006). What is TRIZ? The TRIZ Journal, Available from: http://www.triz-journal.com/archives/what_is_triz/

E Berty – (2011) Cigarette Reject Rate Reduction using a Lean Six Sigma Approach kth.diva-portal.org

Bovarnick, E. (2006). The power of Lean Six Sigma: The Nortel journey. http://www.nortel.com/corporate/investor/events/investorconf/collateral/breakout_leansix sigma_no16.pdf.

Britz, Emerling et al (2000) Improving Performance Through Statistical Thinking , QASQ, Wisconsin

Browne and Keeley (2004) Asking the right questions. Prentice-Hall: Englewood Cliffs, NJ.

Brunet, A.P. and New, S. (2003), "Kaizen in Japan: an empirical study", International Journal of Operations & Production Management, Vol. 23 No. 12, pp. 1426-1446.

Cameron, G., (2010). TRIZICS: Teach yourself TRIZ, how to invent, innovate and solve ‘‘impossible’’ technical problems systematically CreateSpace, Scotts Valley, CA.

W Chandra, TN Goh (2002) INTRODUCING SIX SIGMA: A FRAMEWORK FOR QUALITY MANAGEMENT xa.yimg.com

Chase & Aquilona (1989) Production and Operations Management: A Life Cycle Approach, 5th edn. Homewood. IL, Irwin

Cheng, J., (2009). Six sigma and TQM in Taiwan: an empirical study of discriminate analysis. Total Quality Management & Business Excellence, 20 (3), 311–326.

Chowdhury, Subir (2005). The Ice Cream Maker: An Inspiring Tale About Making Quality The Key Ingredient in Everything You Do. New York: Doubleday, Random House. ISBN 978-0-385-51478-1.

Counterfactuals, Harvard University Press 1973; revised printing Blackwell 1986.

Crosby, Philip (1979). Quality is Free. New York: McGraw-Hill. ISBN 0-07-014512-1.

Dalibor Petkovi & Mirna Issa & Nenad D. Pavlovi & Lena Zentne (2013) Application of the TRIZ creativity enhancement approach to design of passively compliant robotic joint Int J Adv Manuf Technol (2013) 67:865–875 DOI 10.1007/s00170-012-4530-4

Daudelin, M. W. (1996), "Learning from Experience through Reflection", Organizational

Doane, D. B. (1987). Explanation of 8D Problem Solving (Eight Disciplines). Retrieved 28 5 2012, http://www.12manage.com/methods_ford_eight_disciplines_8D.html

Domb, E., (1998). QFD and TIPS/TRIZ. The TRIZ Journal. (June 1998). Available from http://www.trizjournal.com/archives/1998/06/c/index.htm

Dourson, S.,(2004). The 40 inventive principles of TRIZ applied to finance. The TRIZ Journal. (October 2004). Available from: /http://www.triz-journal.com/archives/2004/10/07.pdf.

Drucker, Peter (1985). Innovation and entrepreneurship. Harper & Row. ISBN 978-0-06-091360-1.

Dynamics, American Management Association, vol. 24, no. 3, pp. 36-48.

Eckes (2001) Eckes, G.(2001) The Six Sigma Revolution . Wiley NY page 5

Eckes (2001) The Six Sigma Revolution, John Wiley & Sons, USA

Edwards Deming, W. (1986). Out of the Crisis. Cambridge, Mass.: Massachusetts Institute of Technology, Center for Advanced Engineering Study. ISBN 0-911379-01-0.

Elias, Victor (2015). The Quest for Ascendant Quality: An Introduction to Contemporary Philosophy and Methods for Strategically Orchestrating the Transformation Towards & Beyond Quality Excellence in Everything you do. Sparta, NJ U.S.A: On QUEST. p. 51.

Eversheim, W., (2009). Innovation Management for Technical Products: Systematic and Integrated Product Development and Production Planning. Springer-Verlag, Berlin Heidelberg.

Ezickson, J.W., (2005). Deploying innovation and inventive thinking in organisations — applying TRIZ to non-technical fields of business. Paper presented at TRIZCON 2005.

Available from: / http://www.aitriz.org/articles/InsideTRIZ/30393033-457A69636B736F6E.pdf

Fathian M, Mahdavi Pour SH (2008) “Principles and management of information technology”, 7th edition, Iran University of Science & Technology Publications

Fey, V., Rivin, E.I., (2005). Innovation on Demand: new product development using TRIZ. Cambridge University Press, Cambridge, UK.

Fisher M. Process improvement by poka-yoke. Work Study 1999; 48(7):264–266.

Four Methods for Completing the Conceptual Development Phase of Applied Theory Building Research in HRD

Fu-Kwun Wanga,b and Kao-Shan Chen (2010) Applying Lean Six Sigma and TRIZ methodology in banking services Total Quality Management Vol. 21, No. 3, March 2010, 301–315

Gadd, K., (2011). TRIZ for Engineers. John Wiley & Sons, West Sussex, UK.

Garvin (1984) What does product quality really mean? Sloan Management Review. Fall, pp 25-43.

Garvin (1987) Competing on the eight dimensions of quality, Harvard Business Review, Nov/Dec.

Ghobadian et al (1994) Gurus of quality: a framework for comparison. Total Quality Management, Vol. 5, No 3, 1994

Frank Bunker Gilbreth, Lillian Moller Gilbreth (1921) Process Charts. American Society of Mechanical Engineers.

Goh, T.N., et al., (2003). Impact of six sigma implementation on stock price performance. Total Quality Management & Business Excellence, 14 (7), 753–763.

Green, F., (2006). Six sigma and the revival of TQM. Total Quality Management & Business Excellence, 17 (10), 1281–1286.

Groocock, J.M. (1986) The Chain of Quality: Market Dominance through Superior Product Quality, Wiley

Guba, E.G. (1981) Criteria for assessing the trustworthiness of naturalistic inquires Educational Resources Information Center Annual Review Paper 29, pp.76-91

L.J. Gutierrez, O.F. Bustinza and V. Barrales Molina.,(2012). Six sigma, absorptive capacity and organisational learning orientation. International Journal of Production Research Vol. 50, No. 3, 1 February 2012, 661–675

Hann, G.J., et al., (1999). The impact of six sigma improvement – a glimpse in the future of statistics. The American Statistician,53 (3), 208–215.

Harry, M.J. (1998). Six Sigma: A breakthrough strategy for profitability. Quality Progress 31, no. 5:60-64.

Harry, M.J., (2000). Six sigma. New York: Currency.

Heck, D.. Quality Progress Volume: 38 Issue 5 (2005) ISSN: 0033-524X

Hoerl, R.W and Snee, R.D. (2002). Statistical Thinking: Improving Business Performance. Pacific Grove, CA: Duxbury Press

http://mikeljharry.com/media/1986_03.pdf

http://mikeljharry.com/milestones.php

http://processmasterywithleansixsigma.com/military-problem-apprecition-process/

http://www.everyspec.com/MIL-STD/MIL-STD-1500-1599/MIL_STD_1520C_1489/

http://www.xtriz.com/publications/AccelerateInnovationWithTRIZ.pdf

https://blog.gembaacademy.com/2007/06/11/need-help-making-decisions/

https://blog.gembaacademy.com/2007/06/11/need-help-making-decisions/

https://www.isixsigma.com/wp-content/uploads/2016/12/Process-Mean-Shift-of-1.5-Sigma-and-Defect-Rate-Corresponding-to-4.5-Sigma-1.gif

https://www.qualitydigest.com/feb04/articles/06_article.shtml

Y Inagaki, H Sugie, H Aisu, S Ono (1995) Behavior-based intention inference for intelligent robots cooperating with human… - Fuzzy Systems, 1995. …, 1995 - ieeexplore.ieee.org

Ishikawa, K (1985) What is Total Quality Control? The Japanese Way, London, Prentice-Hall

J Li, K Zhang (2007) Keyword extraction based on tf/idf for Chinese news document, Wuhan University, Journal of Natural Sciences, 2007 - Springer

Jafari A, Pour Kheradmand R (2003) “Familiarization whit the concepts and method of executing kaizen in service and industrial units”, Report of KAIZEN Training Workshop in Tage Company

T Juravich, K Bronfenbrenner (2003) Out of the ashes: the steelworkers' global campaign at Bridgestone/Firestone books.google.com

Kanji, G, & Asher, M 1993, 'Problem-solving', Total Quality Management, pp. 51-57, Business Source Complete, EBSCOhost, viewed 24 May 2017.

Kano, Noriaki (1984-04-01). "Attractive quality and must-be quality". The Journal of the Japanese Society for Quality Control: 39–48.

X Ke, Q Guo, Y Zhang, P Gao (2009) Multi-scale terrain representation and terrain analysis proceedings.spiedigitallibrary.org

Knowledge to Information Search: An Application of Process Theory to the Indian Market",

Krajnc, M. (2012) With 8D method to excellent quality, Journal of Universal Excellence, Professional Article October 2012, Year 1, No. 3, pp. 118–129.

Krefting, L. (1990) Rigor in Qualitative Research: The Assessment of Trustworthiness American Journal of Occupational Therapy March 1991 vol. 45 no. 3 pp. 214-222

Ladkin and Loer (1998) Why-Because Analysis: The formal logic of failure, RVS – Bk-98-01.

LEE Sangjin, H In-Hwa (2006) DRBAC Model Using a WSNM for Services in-Home- IEICE transactions on information and …, 2006 - search.ieice.org

Lincoln, Y.S & Guba F.A (1985) Naturalistic inquiry Beverley Hill CA Sage

Linderman, K.,R.G. Schroeder, S. Zaheer and A.S. Choo, (2003). Six sigma: A goal-theoretic perspective. J. Oper. Mange.,21:193-203.

Litvin, S., Petrov, V., Rubin, M., Fey, V., (2005). TRIZ body of Knowledge.

Liu, Y., Li, K.,and Mclean, A., (2013) Six Sigma Approach to Performance Management. Journal of Applied Sciences 13 (22): 5309-5317, 2013.

Livotov, P., (2008). TRIZ and Innovation Management. Available from:/http://www.triz.it/triz_papers/2008 20TRIZ 20and 20Innovation 20Management.pdf

Llorens, F.J. and Molina, L.M.,(2006). Six sigma and management theory: processes, content and competitiveness. Total Quality Management & Business Excellence, 17 (4), 485–506.

Lucas, M.L., (2002). The essential six sigma: how successful six sigma implementation can improve the bottom line. Quality Progress, 35 (1), 2–32.

Lucier, G.T. and Seshadri, S.,(2001). GE takes Six Sigma beyond the bottom line. Strategic Finance, 82 (11), 40–46.

LWD 5-1-4 – The Military Appreciation Process, 2009

Manimay Ghosh (2012) A3 Process: A Pragmatic Problem-Solving Technique for Process Improvement in Health Care 14: 1 Journal of Health Management

Mann, D., Domb, E., (1999). 40 Inventive (Business) Principles With Examples. The TRIZ Journal (September 1999). Available from: /http://www.trizjournal.com/ archives/1999/09/a/index.htm

Marquis, H (2010) Thinking About Problems: Kepner-Tregoe Retrieved October 22, 2013 http://www.itsmsolutions.com/newsletters/DITYvol6iss19.htm Vol. 6.19 • May 15, 2010

Marsh, D.G., Waters, F.H., Marsh, T.D., (2004). 40 Inventive Principles with Applications in Education. The TRIZ Journal. (April 2004). Available from:/http://www.triz-journal.com/archives/2004/04/04.pdf

Masaaki imai, Kaizen: The Key to Japan’s Competitive Success, Random House, 1986, p. 60.

Mason, M. (2010). Sample Size and Saturation in PhD Studies Using Qualitative Interviews [63 paragraphs]. Forum Qualitative Sozialforschung / Forum: Qualitative Social Research, 11(3), Art. 8, http://nbn-resolving.de/urn:nbn:de:0114-fqs100387.

Matthews and Ross (2010) Research Methods: A Practical Guide for the Social Sciences Pearson Education, Limited

Matthews, Daniel D. (2011): The A3 Workbook - Unlock your problem-solving mind, Productivity Press - 183 Pages

Mays et al (2001) Mays, N., Roberts, E. and Popay, J. (2001), Synthesising Research Evidence, In N. Fulop, P. Allen,A. Clarke and N. Black (eds) ed, Studying the Organisation and Delivery of Health Services:Research Methods., London: Routledge.

McNiff, J., & Whitehead, J. (2000). Action research in organisations. London: Routledge.

K Meyer (2010) "Diving into reading": revisiting reciprocal teaching in the middle years-eprints.qut.edu.au

E Michlowicz, B Karwat (2010) Implementation of Total Productive Maintenance–TPM in an enterprise Scientific Journals Maritime, University of Szczecin 2010, 24(96) pp. 41–47

MIL-STD-1520C, MILITARY STANDARD: CORRECTIVE ACTION AND DISPOSITION SYSTEM FOR NONCONFORMING MATERIAL (24 JUN 1986) Retrieved October 22, 2012 http://www.everyspec.com/MIL-STD/MIL-STD-1500-1599/MIL_STD_1520C_1489/

Mish, D.C.A. (2012) Self-Disclosure on Social Networking - wpi.edu Retrieved November 8,2013http://www.wpi.edu/Pubs/E-project/Available/E-project-030112-142437/unrestricted/Self_Disclosure_IQP_Paper_Redacted.pdf

Moehrle, M. G. (2005). What is TRIZ? From conceptual basics to a framework for research. Creativity and Innovation Management 14 (1), 3–13.

Moehrle, M.G., (2005). What is TRIZ? From conceptual basics to a framework for research. Creativity and Innovation Management 14 (1), 3–13.

Montgomery DC.,(2004). Selecting the Right Improvement Projects. Quality and Reliability Engineering International 2004; 20(7):iii–iv

Moorhead G, Griffin R (2008) "Organizational behavior", Translated by S.M. Alvani and G. Memarzadeh, 13th edition, Morvarid

Mottagi H (2009) "Management of Production and Operations", 7th edition, Avay-e-Patris

Nael MK (2003) "Application of fish bone chart", Tadbir, Scientific-Educational Journal, 14th Years, No. 141, pp 25-32 12.

Nakagawa, T., (2001). Introduction to TRIZ (Theory of Inventive Problem Solving): A technological Philosophy for Creative Problem Solving. Paper presented at The Twenty third Annual Symposium of Japan Creativity Society, Tokyo University, Tokyo. November 3–4, 2001. Available from:/http://www.osaka-gu.ac.jp /php/ nakagawa/ TRIZ/ eTRIZ/ epapers/ eIntro011223/eIntroJCS011104.html

Ohno (1988) Taiichi Ohno; foreword by Norman Bodek (1988). Toyota production system: beyond large-scale production. Portland, Or: Productivity Press. ISBN 0-915299-14-3.

Osborn, A. 1942. How to think up. New York: McGraw Hill.

Osborn, A. 1963. Applied imagination. New York: Charles Scribner's Sons.

Pande el al (2000), The Six Sigma Way, McGraw-Hill, NY page 260

Pannenbaecker, T., (2001). Methodisches Erfinden in Unternehmen: Bedarf, Konzept, Perspektiven fur TRIZ-basierte Erfolge (Vol. Wiesbaden): Gabler. In

JH Park, JS Park, SJ Lee, BS Koh (2006) A DRBAC model based on context for smart and secure services in intelligent ubiquitous home- Ubiquitous Intelligence and …, 2006 - Springer

Pereira (2007) The Cause & Effect Matrix Retrieved October 22,2013 http://lssacademy.com/2007/06/11/need-help-making-decisions/

Petrovi, S. M., et al.(2014) , TRIZ Method Application for Improving the Special Vehicles THERMAL SCIENCE: Vol. 18, Suppl. 1, pp. S13-20

Pirsig, Robert M. (1974). Zen and the art of motorcycle maintenance : an inquiry into values. New York, N.Y.: Morrow. ISBN

Processes", In Proceedings of Design2, May 14 - 17, Dubrovnik.

Productivity Development Team (2003) Identifying waste on the shopfloor (Productivity Press) books.google.com

Pulakanam, V., (2012). Costs and Savings of Six Sigma Programs: An Empirical Study. Quality Management Journal 2012, Vol.19 Issue 4, p39-54.

Quality, (2012). The life and death of Six Sigma (and its training). Quality Nov2012, Vol. 51 Issue 11, p16-17. 2p

Rademeyer, A., Du Plessis, Y., & Kepner, C.H. (2009). Human performance variation analysis: A process for human performance problem solving. SA Journal of Human Resource Management/SA, Vol7 (1), Art. #174, 9

Rantanen & Domb (2002) Simplified TRIZ, CRC Press LLC

Rantanen, K., Domb, E., (2008). Simplified TRIZ — new problem solving applications for engineers and manufacturing professionals. Auerbach Publications,New York.

Rea, K., (2001). TRIZ and software — 40 principle analogies, Part 1. The TRIZ Journal. (September 2001). Available from: /http://www.triz-journal.com/ archives/ 2001 /09/e/index.htm

Reid and Sanders (2013), Operations Management, Wiley page 138-149

Retseptor, G., (2005). 40 inventive principles in marketing, sales and advertising.

Retseptor, G., (2007). 40 inventive principles in customer satisfaction enhancement.

Reymen, I.M.M.J. and Hammer, D.K. (2002), "Structured Reflection for Improving Design

Robin Kent 2017

Rooney and Heuvel (2004) Root cause analysis for beginners, America Society for Quality, Quality Progress 37(7): pp. 45-53

Ross, V., (2006). VizTRIZ: a visual approach to the contradiction matrix. The TRIZ Journal. (November 2006). Available from: /http://www.triz-journal.com/archives/2006/11/02.pdf.

Rutitsky, D., (2010). Using TRIZ as an entrepreneurship tool. Journal of Management 17 (1), 39–44.

Sandelowski, M (1986) The problem of rigor in qualitative research. Advances in Nursing Sciences 8, pp. 27-37.

Savranksy, S.D., (2000). Engineering of creativity —introduction to TRIZ methodology of inventive problem solving. CRC Press, Boca Raton, Florida.

Schroeder et al (2008) Six Sigma: definition and underlying theory. Journal of Operations Management 26 (4), pp 536-554

Shainin R.D. (1993) “Strategies for Technical Problem Solving”, Quality Engineering, 5,pp. 433-438.

Shamji, N., (2005). Six sigma basics. Total Quality Management, 16 (5), 567–574.

Slocum, M.S., Kermani, A.H.M., (2006). Case study: integrating TRIZ into six sigma.The TRIZ Journal, Available from:/http://www.triz-journal.com/content/c070319a.asp.

Snee, R.D.,and R.W. Hoerl.(2004). Six Sigma beyond the factory floor: Deployment strategies for financial services, health care, and the rest of the real economy. Upper Saddle River, NJ:FT Press

Sobek & Smalley (2008): Understanding A3 Thinking, Productivity Press

Sobek, D. K. (2010) http://www.lean.org/common/display/?o=112 reviewed on 2/2/2014

Souchkov, V.(1997). Accelerate innovation with TRIZ. Available from:/

Souchkov, V., (2008). A brief history of TRIZ. Available from:www.xtrix.com/

Steiner, Stefan H., R. Jock MacKay, and John S. Ramberg. (2008) "An Overview of the Shainin System TM for Quality Improvement." Business and Industrial Statistics Research Group (BISRG), Department of Statistics and Actuarial Sciences, University of Waterloo, Waterloo, Canada

Julia Storberg-Walker, Thomas J. Chermack HUMAN RESOURCE DEVELOPMENT QUARTERLY, vol. 18, no. 4, Winter 2007 © Wiley Periodicals, Inc. Published online in Wiley InterScience (www.interscience.wiley.com) • DOI: 10.1002/hrdq.1217

TC 176/SC (2005). ISO 9000:2005, Quality management systems -- Fundamentals and vocabulary. International Organization for Standardization.

The TRIZ Journal. (April 2005). Available from:/http://www.triz-journal.com/ archives/ 2005/04/01.pdf

The TRIZ Journal. (January 2007). Available from:/http://www.triz-journal.com/archives/2007/01/04/

Ungvari, S., (1999). TRIZ within the context of The Kano Model. The TRIZ Journal (October 1999). Available from http://www.triz-journal.com/archives/1999/ 10/e/index.htm.

Van Iwaarden, I., et al., (2008). The six sigma improvement approach: a transnational comparison. International Journal of Production Research, 46 (23), 6739–6758.

Walliman, N.S.R (2001) Your Research Project: A step-by-step guide for the first time researcher by London : Sage Publications Ltd

Walton, Mary; W. Edwards Deming (1988). The Deming management method. Perigee. p. 88. ISBN 0-399-55000-3.

C Wang, M Zhang, L Ru, S Ma (2008) An automatic online news topic keyphrase extraction system WI-IAT'08. IEEE/WIC/ …, 2008 - ieeexplore.ieee.org

Wayne G. Macpherson, James C Lockhart, Heather Kavan, Anthony L. Iaquinto, (2015) "Kaizen: a Japanese philosophy and system for business excellence", Journal of Business Strategy, Vol. 36 Issue: 5, pp.3-9, doi: 10.1108/JBS-07-2014-0083 Permanent link to this document: http://dx.doi.org/10.1108/JBS-07-2014-0083

Whittemore, R. and Knafl, K. (2005), "The Integrative Review: Updated Methodology", Journal of Advanced Nursing, vol. 52, no. 5, pp. 546– 553.

Womack, Jones, Roos; The Machine That Changed The World, Rawson & Associates, New York. Published by Simon & Schuster, 1990.

Wright, J.K (1995) You can meet the competition with world-class problem-solving. Business Journal Serving Southern Tier, CNY, Mohawk Valley, Finger Lakes, North, 10503005, 9/18/95, Vol. 9, Issue 19

XHB Le, A Kashif, S Ploix, J Dugdale (2010) Simulating inhabitant behaviour to manage energy at home researchgate.net

Yoon, H., (2009). Pointers to effects for non-technical problem solving. The TRIZ Journal. (March 2009). Available from: /http://www.triz-journal.com/archives/2009/03/03/

Zhang, J., Chai, K., Tan, K., (2003). 40 inventive principles with applications in service operations management. The TRIZ Journal. (December, 2003). Available from: /http://www.triz-journal.com/archives/2003/12/d/04.pdf .

Zinck, W. Clements (1971) Dynamic Work Simplification p. 122, Krieger Publishing, USA

Zlotin, B., Zusman, A., Kaplan, L., Visnepolschi, S., Proseanic, V., Malking, S., (2000). TRIZ beyond technology: the theory and practice of applying TRIZ to non- technical areas, Available from http://www.trizmantra.com/Learning 20Resource 20files/ TRIZ_Beyond_Technology.pdf

Appendix 1 – Research Method (including Ethical Approval)

The raw data is available on request.

Committee on Research Ethics

PARTICIPANT CONSENT FORM

Title of Research Project:	A review of quality improvement techniques from World War II to the current day – is there a missing link to ensure a clearer and concise process for quality improvement? (The 5W&1H method)
Researcher(s):	**Jonathan Smyth- Renshaw**

Please initial box

1. I confirm that I have read and have understood the information sheet dated [DATE] for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my rights being affected. In addition, should I not wish to answer any particular question or questions, I am free to decline. ☐
3. I understand that, under the Data Protection Act, I can at any time ask for access to the information I provide and I can also request the destruction of that information if I wish. ☐
4. I agree to take part in the above study. ☐

Participant Name	Date	Signature
Name of Person taking consent	Date	Signature
Researcher	Date	Signature

Principal Investigator:
Name Jonathan Smyth-Renshaw
Work Address
Work Telephone
Work Email smythrenshaw@btinternet.com

Student Researcher:
Name
Work Address
Work Telephone
Work Email

[V2 24/03/16]

UNIVERSITY OF LIVERPOOL

Committee on Research Ethics

PARTICIPANT CONSENT FORM

Title of Research Project:	A review of quality improvement techniques from World War II to the current day – is there a missing link to ensure a clearer and concise process for quality improvement? (The 5W&1H method)
Researcher(s):	**Jonathan Smyth- Renshaw**

Please initial box

1. I confirm that I have read and have understood the information sheet dated [DATE] for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. SB

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my rights being affected. In addition, should I not wish to answer any particular question or questions, I am free to decline. SB

3. I understand that, under the Data Protection Act, I can at any time ask for access to the information I provide and I can also request the destruction of that information if I wish. SB

4. I agree to take part in the above study. SB

Suzanne Bonnett 27-4-16 SBonnett

Participant Name Date Signature

Suzanne Bonnett 27.4.16 SBonnett

Name of Person taking consent Date Signature

Researcher Date Signature

Principal Investigator:
Name Jonathan Smyth-Renshaw
Work Address
Work Telephone
Work Email smythrenshaw@btinternet.com

Student Researcher:
Name
Work Address
Work Telephone
Work Email

[V2 24/03/16]

UNIVERSITY OF LIVERPOOL

Committee on Research Ethics

PARTICIPANT CONSENT FORM

Title of Research Project:	A review of quality improvement techniques from World War II to the current day – is there a missing link to ensure a clearer and concise process for quality improvement? (The 5W&1H method)
Researcher(s):	**Jonathan Smyth- Renshaw**

Please initial box

1. I confirm that I have read and have understood the information sheet dated [30/3] for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ✓
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my rights being affected. In addition, should I not wish to answer any particular question or questions, I am free to decline. ✓
3. I understand that, under the Data Protection Act, I can at any time ask for access to the information I provide and I can also request the destruction of that information if I wish. ✓
4. I agree to take part in the above study. ✓

James Derby	30/3/16	J. Derby
Participant Name	Date	Signature
James Derby	30/3/16	J. Derby
Name of Person taking consent	Date	Signature
Jonathan Smyth-Renshaw	30/3/16	[signature]
Researcher	Date	Signature

Principal Investigator:
Name Jonathan Smyth-Renshaw
Work Address
Work Telephone
Work Email smythrenshaw@btinternet.com

Student Researcher:
Name
Work Address
Work Telephone
Work Email

Participant Information Sheet

1. **Title of Study**
   A review of quality improvement techniques from World War II to the current day – is there a missing link to ensure a clearer and concise process for quality improvement?

2. **Invitation Paragraph**
   You are being invited to participate in a research study. Before you decide whether to participate, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and feel free to ask us if you would like more information or if there is anything that you do not understand. We would like to stress that you do not have to accept this invitation and should only agree to take part if you want to. If you agree then you are free to withdraw at any time. Thank you for reading this.

3. **What is the purpose of the study?**
   The researcher has undertaken a review of quality improvement techniques from World War II to the current day. During this review, there is evidence to support the hypothesis that there is missing link in the thought process used to improve quality in the existing techniques. The researcher, based on the literature review, has developed a method/process to address this missing link. The method is called the '5W&1H' method in which the W's are 'where on the product', 'where in the process', 'who', 'what', 'when' and the H is 'how'. The method allows quality improvement tasks to be well defined and this increases the likelihood of a successful outcome in the task. The researcher is now in a position where the method is ready for testing in a number of different business situations. The researcher has identified a small number of companies, who he works with in his capacity as a consultant, to trial the method on quality improvement tasks. The approval is to allow the application of the method within the selected company to test the research hypothesis established in the literature review. The data that will be collected from the companies is the how the '5W&1H' method has been used to solve a problem relevant to that company. The method will be deployed by the company with guidance, if required, from the researcher. The data collected will be presented as a case study in the researcher's thesis.

4. **Why have I been chosen to take part?**
   You have been selected as you are an employee in a company who have been trained in the method described in the research. Your company will be one of up to ten other companies.

5. **Do I have to take part?**
   You and your company are participating and it is voluntary and that you and your company are free to withdraw at anytime without explanation and without incurring a disadvantage.

6. **What will happen if I take part?**
   The questionnaire attached to this form explains in detail the process if you agree to be part of the study. PLEASE ENSURE YOU READ THE QUESTIONNARIE BEFORE AGREEING TO BY PART OF THIS RESEARCH.

7. **Expenses and / or payments**
   No payments will be made by the researcher during the research.

8. **Are there any risks in taking part?**
The method is used to define a quality improvement task using the facts available at the time and then follows a process defined in the research. Within the selected companies there are existing Health and Safety rules which govern business activities. During the use of the research method the task will follow the company rules. Therefore, if in using the method the task involves a risk or a hazard that the company considers to be significant to physical or psychological well-being risk/hazard process will be evaluated and necessary actions will be taken to minimize risk. The potential psychological effects are minimal and the potential physical risks will be considered and will depend on the nature of the task to be undertaken.

9. **Are there any benefits in taking part?**
If proven having learnt and applied the '5W1H' method the research participant will have a method for solving future and unexpected quality issues.

10. **What if I am unhappy or if there is a problem?**
"If you are unhappy, or if there is a problem, please feel free to let us know by contacting the Research Governance Officer at ethics@liv.ac.uk. When contacting the Research Governance Officer, please provide details of the name or description of the study (so that it can be identified), the researcher(s) involved, and the details of the complaint you wish to make."

11. **Will my participation be kept confidential?**
The data will be collected as described on the questionnaire. The data will be shared between the researcher and supervisors at University of Liverpool and be available in the final PhD document.

12. **What will happen to the results of the study?**
The results will be available in the PhD document, which is a public document held by University of Liverpool. There is no plan to publish the company case studies in any other documents.

13. **Who can I contact if I have further questions?**
Jonathan Smyth-Renshaw Business number 0044 7976913118**.**

Appendix 2: - Flow Products Case Study

These sheets detail the instructions for using the 5W&1H method. You have kindly agreed to use the method as part of my PhD research. Prior to the information being added into my final thesis you will be given the opportunity to review the final wording. The second point of note is that you are free to leave the process at any point up to the final thesis document being published. The conditions are detailed on the consent form attached which you need to complete and return to me.

Section 1 : About you and your organisation

Name of Organisation	FLOW PRODUCTS LTD (FLOW GROUP PLC,
Position in the Organisation	PROJECT DIRECTOR / GENERAL MANAGER
Length of time in your current role	2 Yrs.
Length of time in organisation	10 Yrs.
Please provide a brief overview of your organisation	

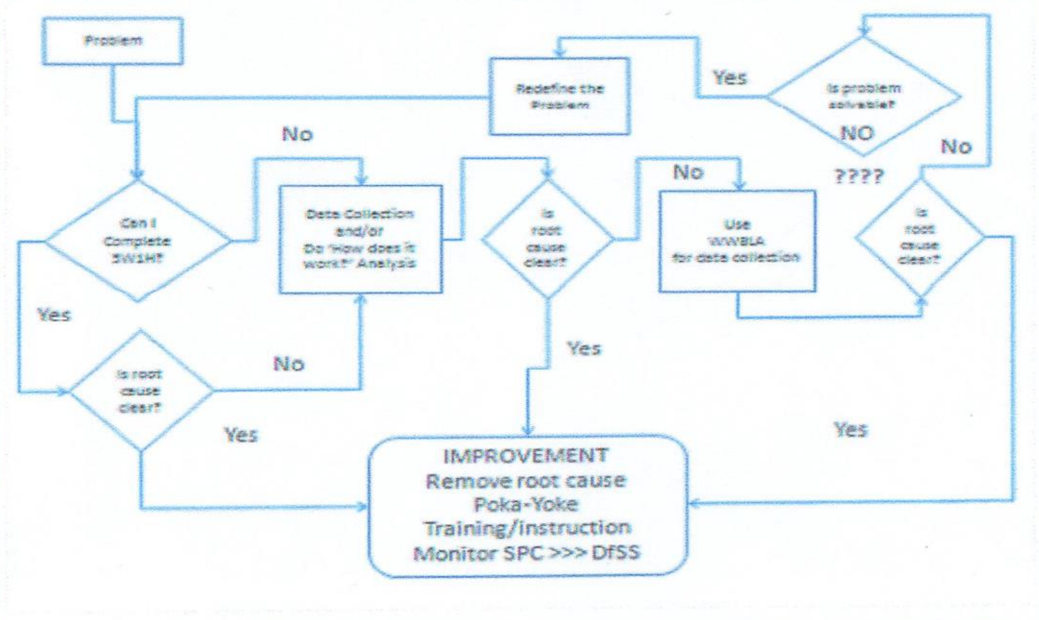
PhD Questionnaire v3 (24/03/16)
Jonathan Smyth-Renshaw (00447976913118)
This document is the questionnaire for Jonathan Smyth-Renshaw's PhD research (200777940)
If you find this document and you are not involved, please destroy the document

Section 2 : Problem solving methods within your organisation		
Question	Explanation	Response
Which of the following approaches have you formally implemented as a tool to solve quality problems?	This is help understand the methods used and the effectiveness within the organisation before introducing the 5W&1H method	Please use the table below

Approaches	Frequency			Effectiveness		
	Never	Sometimes	Always	Not effective	Somehow effective	Very effective
Checklist	✓					
Root Cause Analysis		✓		✓		
5 whys		✓		✓		
Problem Analysis Flow Chart		✓		✓		
8 Disciplines			✓			✓
A3 report	✓					
Six Sigma (DMAIC)		✓				✓
Other:	✓					

Section 3 : The application of the 5W & 1H method

The figure below details the 5W&1H method - this is the process you should follow as you try to solve your selected quality problem. Further explanation is given below of the data you are expected to collect.



Data required/(explanation)

The description of the initial problem and the magnitude of the problem to your company for example, cost, loss of orders, customer complaints, loss of time to the business, the list is not exhaustive (this is establishing the magnitude of the problem prior to using the 5W&1H method and if possible describe which quality solving method you would have used to try to solve the problem instead of 5W&1H method)

Response

Section 4 of the project charter within the define statement.

Also stated within Project Risks & Constraints.

Continuous Improvement PROJECT CHARTER	VERSION DATE	22/02/2016	REFERENCE NUMBER	0001A	REVISION	1

PROJECT TITLE	Pre-Production Build Validation and Verification Failures		
PROJECT OWNER	James Derby	PROCESS/AREA OWNER	Validation and Verification
SPONSOR	Peter Sanders	CHAMPION	David Ridley

1. PROCESS/PRODUCT *(the process/product area where there is a improvement opportunity)*

Flow mCHP 14kW/H1.0

2. PROBLEM STATEMENT AND OBJECTIVE *(detail description of current problem)*

The 5W and 1H Method is to be employed to define the problem statement:

- What – The appliances fail the 5 day PPB (Pre-Production Build) V&V (Validation and Verification Test)
- Who – The Validation Manager discovers the failure – Frank Barlow.
- Which – The failure rate is near epidemic with 19 failures out of 22 units V&V tested.
- Where – The problem is seen in the steam circuit. Excess water leakage.
- When – unknown. The problem is only detected at the end of the process when the water loss is measured.
- How – Water loss should be no more that 50ml at the end of the 5 day PPB V&V test. 19 of the 22 units exceed this value.

3. PRIORITY *(Which strategic driver(s) does this project affect and why? E.g. productivity, reliability, quality, cost)*

Greater than 50ml during the V&V will result in an unscheduled customer service call - <12 months. Hence areas affected are reliability and warranty cost.

4. PROJECT SCOPE *(Describe project scope. Where does the process start/finish? What is/is not included in the scope?)*

The objective is to minimise the number of unscheduled <12 month service calls by minimising the water loss. The initial target is to minimise this TARGET is < 50ml. Whilst the final target is < 10ml, this is not the final objective of this project.

5. VISION AND NEXT TARGET CONDITION *(Final vision for process/product area. Next target condition / Future State)*

Final Vision:

Minimise the water loss to <10ml (no steam circuit recharge required within 5 years)

Next Target Condition:

Minimise the water loss to <50ml (no steam circuit recharge required within 12 months)

6. PURPOSE/EXPECTED BENEFITS

1. Improved Reliability.
2. Customer confidence.
3. Reduced warranty cost.

METRICS

See attached data set.

HIGH LEVEL TIMELINE

Project Start Date		Target Completion Date	

Key Dates (PDCA, DMAIC etc)

Item	Date

DEPARTMENTS AFFECTED *(Which departments are involved in this process, which will be affected by any changes?)*	STAKEHOLDERS
Validation	Frank Barlow
Design	Tony Day
Programme Management	Al Beasley
Quality	Peter Sanders
Supply Chain	Gary Holmes
Jabil Manufacturing	Martin Gaffney

SPECIAL SUPPORT AND RESOURCES REQUIRED (What special support and resources are required to complete this project?)	COSTS
None.	

PROJECT RISKS AND CONSTRAINTS	DEPENDENTS AND DEPENDANCIES
Flow are accruing $80k for every week of lost production. Hence it may not be possible to identify the specific cause of the leak. The objective will be to reduce the leak to within the project scope.	

PROJECT TEAM

Name	Role	Organisation
James Derby	Undertake investigation.	
Peter Sanders	Support investigation.	
Tony Day	Design assistance and improvement implementation.	
Frank Barlow	Testing and data collection	

APPROVAL

Sponsor Name:		Date	
Signed:			

Data required/(explanation)
What information is missing to complete the '5W&1H' statement? (detail which of the 5W1H questions have missing data if you have failed to solve the problem)
Response
The 5W1H method described what the problem was. However, it did not determine the root cause.

Data required/(explanation)
For the problem describe 'how does it works?' this should be included and explained (this step may include a video / a detailed step by step map of the process / Plant diagrams)
Response
See ANALYSIS (How does it work?).

Question 3.2: Were you able to solve the problem following this step in the process?	Yes	No
	☐	☑

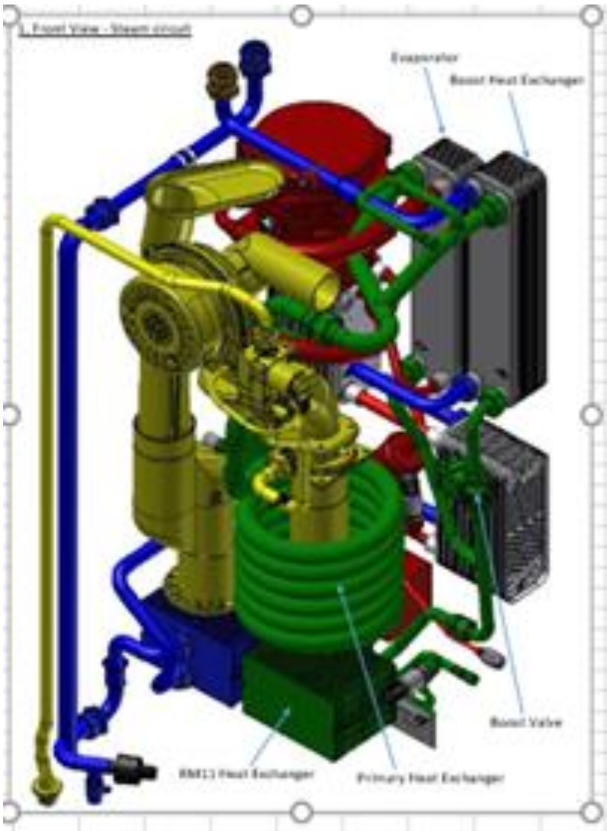
How does it work?

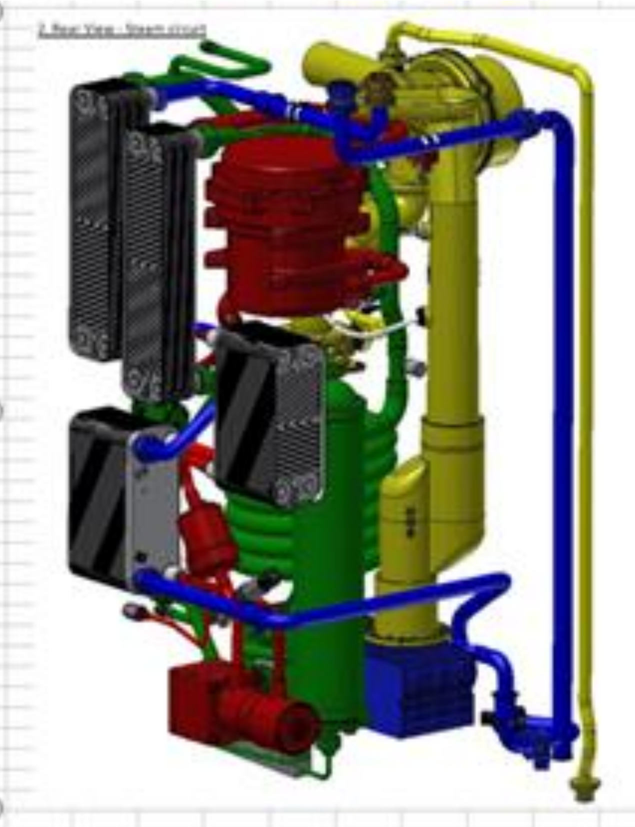
The cad models (1 & 2) below show a front and rear view of the steam circuit within the 14kW/H1.0 mCHP appliance.

The steam circuit is indicated in green.

Steam travel on front view:

From PHE Coil - Top (Primary heat exchanger)
to
parallel connection
to
Boost Heat Exchanger (right) and Evaporator (left)
to
parellel connection (boost valve on Boost Heat Exchanger)
to
RM11 Heat Exchanger
to
PHE Coil - Bottom

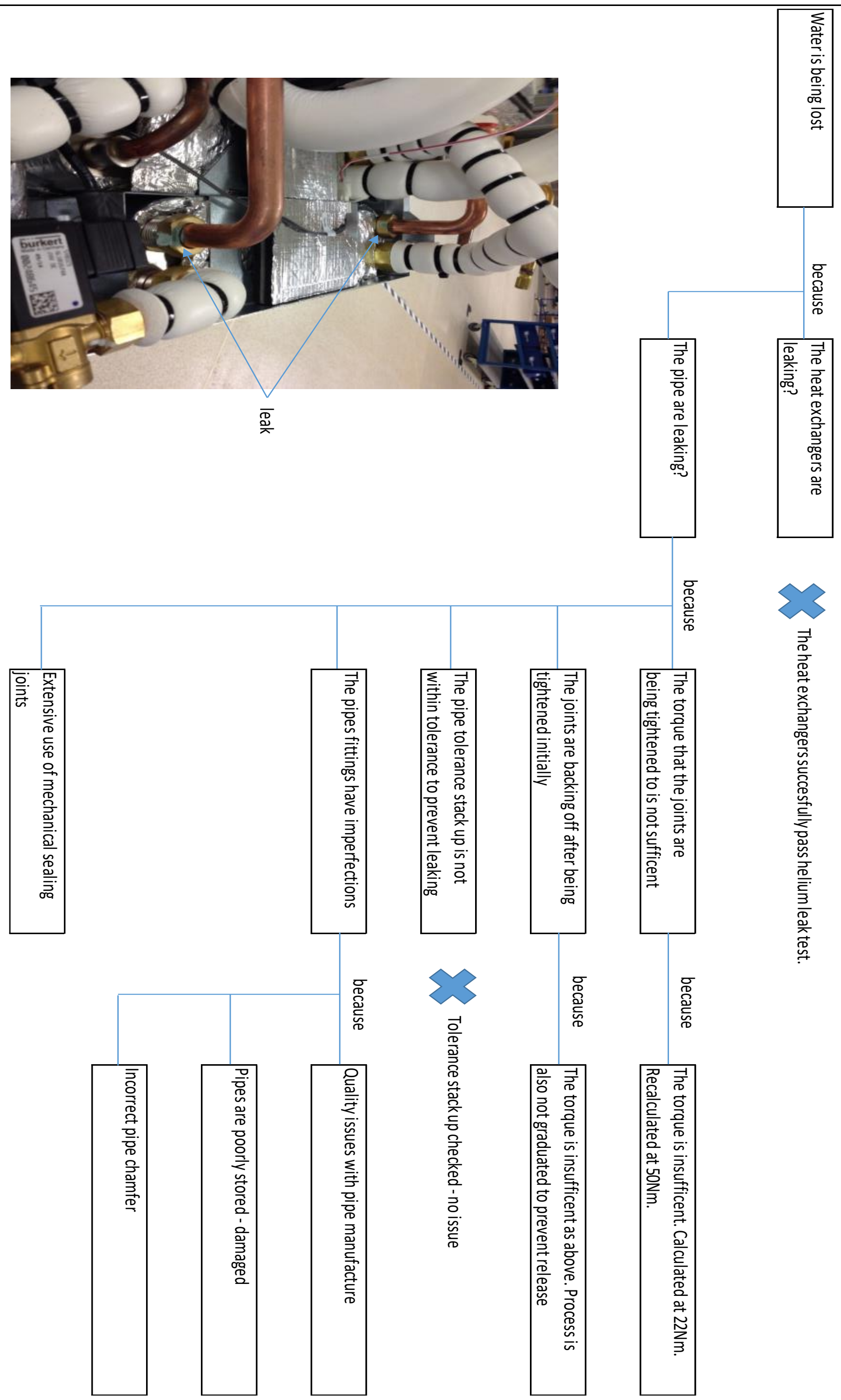




Data required/(explanation)
If you have to use the 'WWLBA' structure this should be included and explained (WWBLA - Why Why Because Logical Analysis is used to list a set of data required which are logical based on the previous steps, it may involve an experiment to collect further data)
Response
See Analysis (WWBLA).

Question 3.3: Were you able to solve the problem following this step in the process?	Yes	No
	✓	

PROBLEM STATEMENT *(Repeated from Project Charter)*
The 5W and 1H Method is to be employed to define the problem statement: · What – The appliances fail the 5 day PPB (Pre-Production Build) V&V (Validation and Verification Test) · Who – The Validation Manager discovers the failure – Frank Barlow. · Which – The failure rate is near epidemic with 19 failures out of 22 units V&V tested. · Where – The problem is seen in the steam circuit. Excess water leakage. · When – unknown. The problem is only detected at the end of the process when the water loss is measured. · How – Water loss should be no more that 50ml at the end of the 5 day PPB V&V test. 19 of the 22 units exceed this value.




Surface imperfections
Damaged pipe
Incorrect chamfer

Data required/(explanation)
The root cause of the problem should be detailed and a direct cause and effect link between the initial problem and the root cause should be shown and explained (This question will detail the root cause and the link to initial problem)
Response
See ANALYIS (WWBLA).

Data required
The solution should be explained and it should be implemented
Response
(See Improve (Test Instruction). Please remove FLOW HEADER.

Work Shop Request Form					
Project	Unit 5 Validation and Verification Testing - Steam Circuit Leak Investigation				
Project Owner	James Derby	Date		Reference	0001A

Technician	Frank Barlow	Date	

Work Instruction

1. The following appliances and power modules are to be reworked in accordance with drawing/instruction GL101843 & GL101843E:

Power Module	Appliances
AN102000-JV00.000516000125	PM102100-EV00.000616000117
AN102000-JV00.000616000135	PM102100-EV00.000616000123
AN102000-JV00.000516000128	PM102100-EV00.000616000121
AN102000-JV00.000516000129	PM102100-EV00.000616000119

2. The following units are to pass through Unit V&V test and the leak rate measured as follows:

Current	**Modified**
Steam Circuit leak 5 day V&V (ml)	Steam Circuit leak 5 day V&V (ml)
290	20
280	20
250	0
50	10

Objective: Measure and confirm **IMPROVEMENT** and define a revised **BASELINE PERFORMANCE** level.

Next Step: Report out stage 2 and seek approval to stage 3

Stage 2 Approval (Yes/No):	Yes
Name	James Derby
Signed	
Date	

3. The following additional appliances and power modules are then to be reworked in accordance with drawing/instruction GL101843 & GL101843E:

Power Module	Appliances
AN102000-JV00.000516000125	PM102100-EV00.000616000117
AN102000-JV00.000616000135	PM102100-EV00.000616000123
AN102000-JV00.000516000128	PM102100-EV00.000616000121
AN102000-JV00.000516000129	PM102100-EV00.000616000119

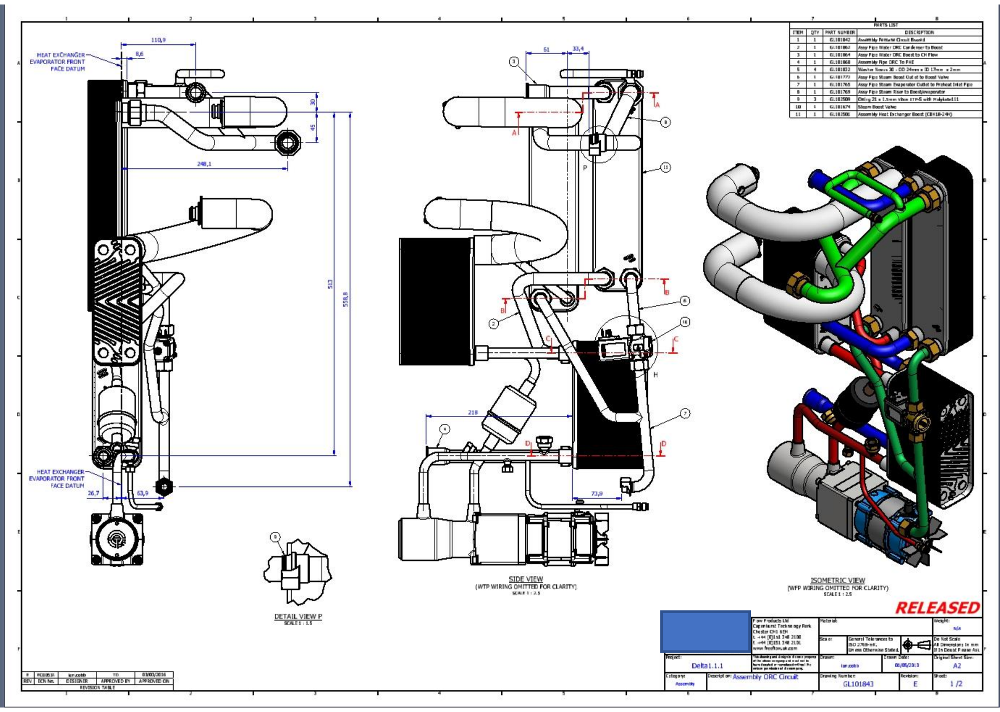
4. The additional units are then to pass through V&V test and the leak measured as follows:

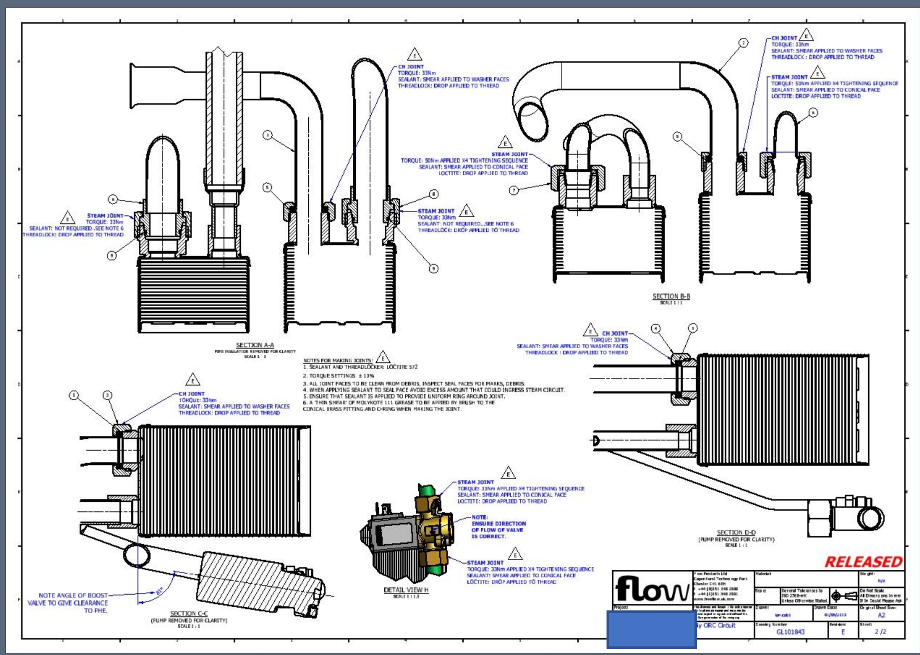
Modified
Steam Circuit leak 5 day V&V (ml)
50
40
0
10

Objective: Re-confirm **IMPROVEMENT** on **ADDITIONAL** units.

Next Step: Report out stage 4

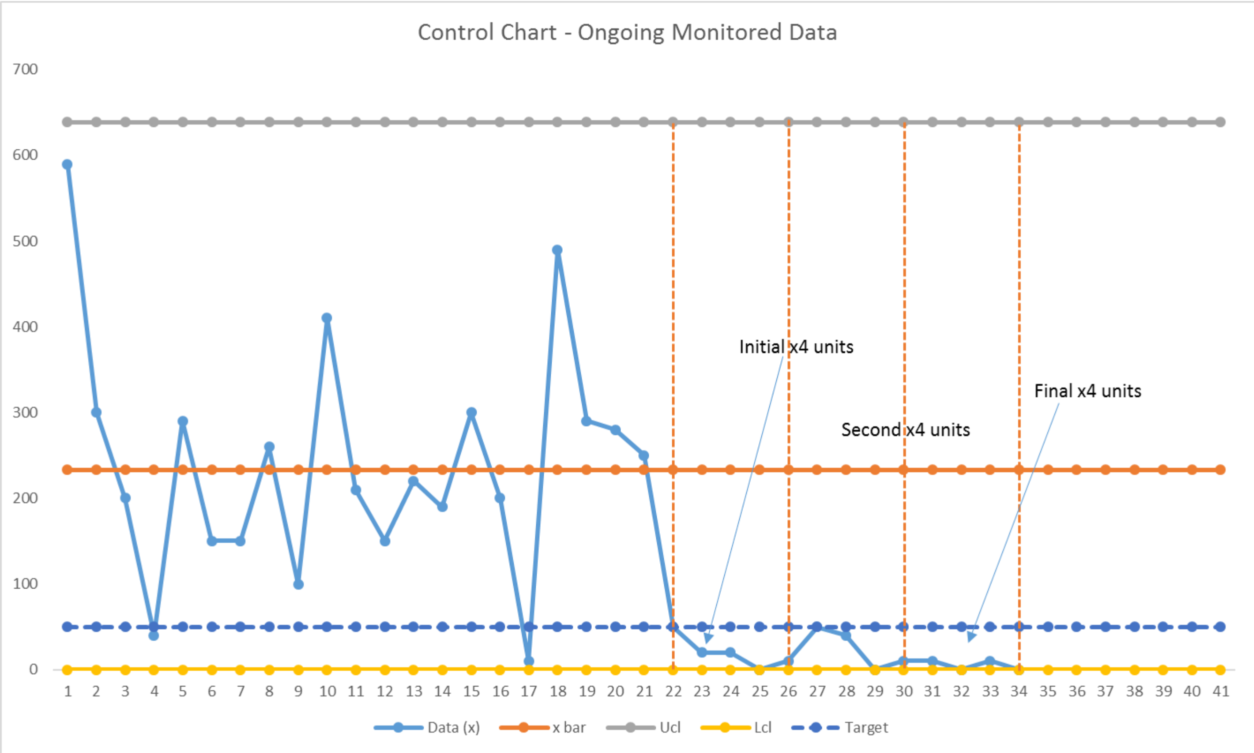
Approval			
Project Owner		Date	
Signed			


HEAT EXCHANGER EVAPORATOR FRONT FACE DATUM
DETAIL VIEW P
SIDE VIEW
(WTP WIRING OMITTED FOR CLARITY)
ISOMETRIC VIEW
(WFP WIRING OMITTED FOR CLARITY)
RELEASED
Delta1.1.1
Assembly ORC Circuit
GL101843
E
1 /2


SECTION A-A
SECTION B-B
SECTION C-C
(PUMP REMOVED FOR CLARITY)
SECTION D-D
(PUMP REMOVED FOR CLARITY)
DETAIL VIEW H
NOTE ANGLE OF BOOST VALVE TO GIVE CLEARANCE TO PHE.
RELEASED
flow
GL101843
E
2 /2

Data required
It should be possible to compare the before and after process for the problem and explain the benefits in full to your company.
Response
See Improve (On going SPC). See Improve (DPMO).

Data required
You should include any other information you feel is relevant including how this method compares to other problem solving methods you have used in your past.
Response
The technique is essentially a three Stage approach:- What is the problem area? What specifically is the problem/root cause(s)? Has the fix worked? Hence effectively a Stage gate approach.



Pre Leak Fix			**Post Leak Fix**		
Defects	19		Defects	0	
Opportunities	22		Opportunities	12	
DPMO	863636.364		DPMO	0	
Sigma rating (short term)	**0.40319644**		Sigma rating (short term)	**#NUM!**	>>>>>6
Sigma rating (long term)	-1.0968036		Sigma rating (long term)	#NUM!	
Quote short term with long term data			Quote short term with long term data		

JABIL **Manufacturing Engineering** flow

Customer: Flow Products

Product: Power Module Assembly

Process: Central Heating and Steam Circuit Rework

IF PRINTED THIS IS A REFERENCE COPY ONLY

Process Owner:	Engineering
Document Author:	David Wards

Review and Approval Body There shall be no alteration to, or deviation from this document without the written approval of the Approval Body.	Engineering	Technical Lead	Manufacturing	Revision

Jabil Confidential and Proprietary Information Page 1 of 16 Revision Electronically Controlled In Share point

Work instruction to ensure improvement is sustained.

Metrics - Raw Data (Pre leak fix)

	Appliance	Power Module	Started testing	Steam Circuit leak 5 day V&V (ml)	Pass/Fail
PPB	AN102000.GV01.024715000107	PM102100.DV02.004715000102	21/11/2015	590	FAIL
	AN102000.GV01.024715000106	PM102100.DV02.004715000101	21/11/2015	300	FAIL
	AN102000.GV01.024715000104	PM102100.DV02.004715000098	22/11/2015	200	FAIL
	AN102000.GV01.024715000105	PM102100.DV02.004715000100	22/11/2015	40	PASS
	AN102000.GV01.024715000109	PM102100.DV02.004715000103	30/11/2015	290	FAIL
	AN102000.GV01.024715000108	PM102100.DV02.004715000105	30/11/2015	150	FAIL
	AN102000.GV01.024715000111	PM102100.DV02.004715000104	30/11/2015	150	FAIL
	AN102000.GV01.024715000103	PM102100.DV02.004715000107	30/11/2015	260	FAIL
	AN102000.GV01.024715000112	PM102100.DV02.004715000106	30/11/2015	100	FAIL
	AN102000.GV01.024715000115	PM102100.DV02.004715000110	09/12/2015	410	FAIL
	AN102000.GV01.024715000114	PM102100.DV02.004715000109	09/12/2015	210	FAIL
	AN102000.GV01.024715000110	PM102100.DV02.004715000099	09/12/2015	150	FAIL
	AN102000.GV01.024715000113	PM102100.DV02.004715000108	10/12/2015	220	FAIL
	AN102000-JV00.000516000123	PM102100-EV00-000416000112	10/02/2016	190	FAIL
	AN102100-JV00.000516000126	PM102100-EV00.000416000113	11/02/2016	300	FAIL
	AN102000-JV00.000516000124	PM102100-EV00.000416000114	12/02/2016	200	FAIL
	AN102000-JV00.000516000130	PM102100-EV00.000416000115	16/02/2016	10	PASS
	AN102000-JV00.000516000131	PM102100-EV00.000416000116	16/02/2016	490	FAIL
	AN102000-JV00.000516000125	PM102100-EV00.000616000117	19/02/2016	290	FAIL
	AN102000-JV00.000616000135	PM102100-EV00.000616000123	19/02/2016	280	FAIL
	AN102000-JV00.000516000128	PM102100-EV00.000616000121	20/02/2016	250	FAIL
	AN102000-JV00.000516000129	PM102100-EV00.000616000119	20/02/2016	50	PASS

Metrics - Raw Data (Post leak fix)

	Appliance	Power Module	Started testing	Steam Circuit leak 5 day V&V (ml)	Pass/Fail
PPB	AN102000-JV00.000516000125	PM102100-EV00.000616000117	25/02/2016	20	PASS
	AN102000-JV00.000616000135	PM102100-EV00.000616000123	25/02/2016	20	PASS
	AN102000-JV00.000516000128	PM102100-EV00.000616000121	25/02/2016	0	PASS
	AN102000-JV00.000516000129	PM102100-EV00.000616000119	25/02/2016	10	PASS
	AN102000-JV00.000516000127	PM102100-EV00.000616000120	09/03/2016	50	PASS
	AN102000-JV00.000516000133	PM102100-EV00.000616000122	09/03/2016	40	PASS
	AN102000-JV00.000616000134	PM102100-EV00.000616000118	10/03/2016	0	PASS
	AN102000-JV00.000616000138	PM102100-EV00.000716000125	11/03/2016	30	PASS
	AN102000-JV00.000616000142	PM102100-EV00.000716000137	16/03/2016	0	PASS
	AN102000-JV00.000716000157	PM102100-EV00.000816000159	16/03/2016	0	PASS
	AN102000-JV00.000816000160	PM102100-EV00.000816000150	16/03/2016	0	PASS
	AN102000-JV00.000816000161	PM102100-EV00.000816000156	16/03/2016	0	PASS

Appendix 3 DMM case study

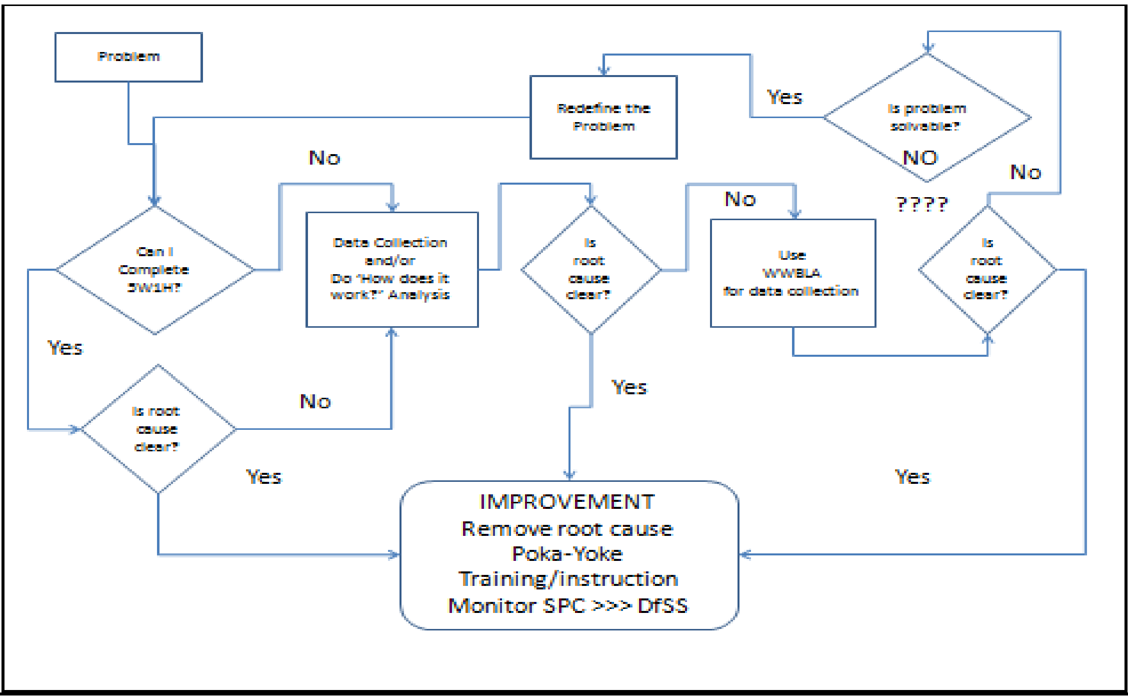
These sheets detail the instructions for using the 5W&1H method. You have kindly agreed to use the method as part of my PhD research. Prior to the information being added into my final thesis you will be given the opportunity to review the final wording. The second point of note is that you are free to leave the process at any point up to the final thesis document being published. The conditions are detailed on the consent form attached which you need to complete and return to me.

Section 1 : About you and your organisation	
Name of Organisation	
Position in the Organisation	
Length of time in your current role	
Length of time in organisation	
Please provide a brief overview of your organisation	Founded in 1981 as Moorhouse Engineering in Bethesda, soon to become DMM and move to more suitable premises in Llanberis in 1986, the company celebrated 30 years of manufacturing in 2011. In 1981 the company employed just 4 people, and now thirty years later we are an important employer in this area with just over 150 men and women on payroll. From the very outset the company has developed products in two main areas; Recreational Climbing and Mountaineering has developed alongside products aimed at the Industrial markets. Both areas complement each other and the areas of overlap benefit both sides. In short, both sides of the business are important to sustain us in the future. Innovation is key to our development, and DMM have continually invested not just in the fabric of the Factory, in plant, machinery, tooling etc but also in ambitious product development plans which can be very costly. However, DMM recognise that it's not sufficient to stand still and copy, DMM need to lead the field in our specialist areas and over the years DMM have done just that and all from our base here in North Wales. DMM have a well-trained and loyal workforce and have amassed a wealth of knowledge over the years which stand us in good stead as one of the leading brands in our field worldwide. DMM have just added a large extension to the Factory site to allow us to lay out a purpose built Assembly area and also a CNC machining area. This was a considerable investment for the company, but as with all DMM's other efforts, it will enable us to be more efficient, competitive, and maintain our unique position as the sole Manufacturer of Climbing Hardware in the UK.

Section 2 : Problem solving methods within your organisation		
Question	Explanation	Response
Which of the following approaches have you formally implemented as a tool to solve quality problems?	This is help understand the methods used and the effectiveness within the organisation before introducing the 5W&1H method	Please use the table below

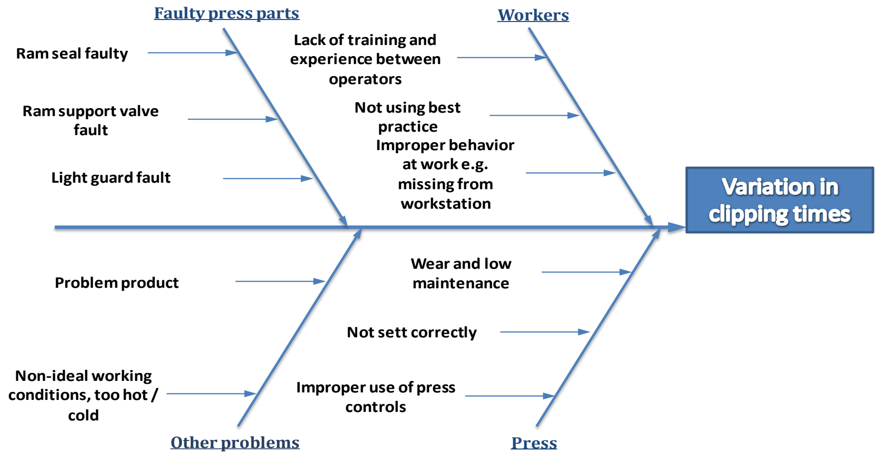
Approaches	Frequency			Effectiveness		
	Never	Sometimes	Always	Not effective	Somehow effective	Very effective
Checklist	√					
Root Cause Analysis		√		√		
5 whys		√		√		
Problem Analysis Flow Chart	√					
8 Disciplines	√					
A3 report	√					
Six Sigma (DMAIC)	√					
Other:	√					

Section 3 : The application of the 5W & 1H method
The figure below details the 5W&1H method - this is the process you should follow as you try to solve your selected quality problem. Further explanation is given below of the data you are expected to collect.



Data required/(explanation)
The description of the initial problem and the magnitude of the problem to your company for example, cost, loss of orders, customer complaints, loss of time to the business, the list is not exhaustive (this is establishing the magnitude of the problem prior to using the 5W&1H method and if possible describe which quality solving method you would have used to try to solve the problem instead of 5W&1H method)
Response

There are five Hare 25 ton hydraulic presses on the shop floor, of which, three are used for clipping; clipping is a term used for removing excess waste from aluminium forgings. The production target is to produce 10 batches of karabiners using the three clipping presses in a 7 ½ hour shift. However, this was not being achieved. Prior to using the 5W&1H process a Cause and Effect diagram had been completed. The initial thought being that the variation was just down to different operators.



Data required/(explanation)

The initial '5W&1H' statement (having used the 5W&1H method please detail the initial statement)

Response

The initial 5W&1H statement is given as follows.

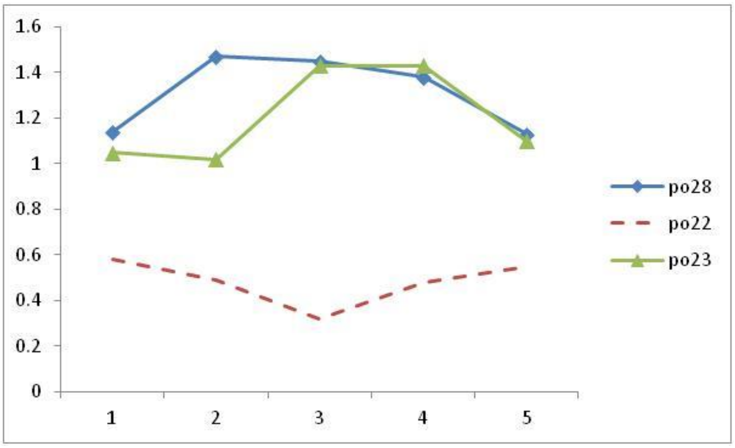
How - Some batches are clipped in under an hour, some take longer.

Who - I found while monitoring operation times on factory master.

What - Clipping the Karabiners.

Where in the process - During the clipping operation?

Saw ⇨ Bend ⇨ Forge ⇨ Solution Treatment ⇨ **Clipping** ⇨ Age ⇨ Vibrate ⇨ Drill ⇨



Y axis – time

X axis – 5 different batches

The graph shows that batches are completed quicker on press PO22 than on PO23 or PO28. Some variation can be explained as the operator to operator effect, the biggest variation shown is between the presses. Further observation of ram travel time on the presses showed that PO22's ram was faster than PO28 or PO23; this led to an investigation of the various parts of the press which could slow down the ram speed. (The ram function is described in the next section)

Where on the product - There was no problem regarding the product.

When – These press to press differences had been present for a long time. The trend is a lot of variation in timings from press to press.

Question 3.1: Were you able to solve the problem following this step in the process?	Yes	No
	☐	☒

Data required/(explanation)

What information is missing to complete the ‘5W&1H’ statement? (detail which of the 5W1H questions have missing data if you have failed to solve the problem)

Response

How the process works is required.

Data required/(explanation)

For the problem describe ‘how does it works?’ this should be included and explained (this step may include a video / a detailed step by step map of the process / Plant diagrams)

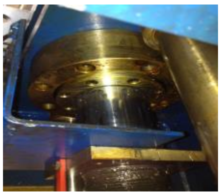
Response

Our presses are Hare HP 25 ton hydraulic presses. The pictures below show the workings of the clipping process.

Hare HP 25 ton clipping press

Ram support valve

Once the press is switched on the motor and hydraulic pump are activated, oil is then pumped up through narrow pipes to an electrically-operated valve block (ram support valve)



Hydraulic ram

This is operated by a PLC module to open and close, as the valve is opened oil is sent through at high pressure to the hydraulic ram, where oil pressure forces the ram down, as the ram reaches the bottom of its stroke the PLC module opens the dump valve to re-direct the oil back to the tank returning the ram to its starting position, completing the cycle of the press.

Question 3.2: Were you able to solve the problem following this step in the process?	Yes	No
	X	

Data required/(explanation)

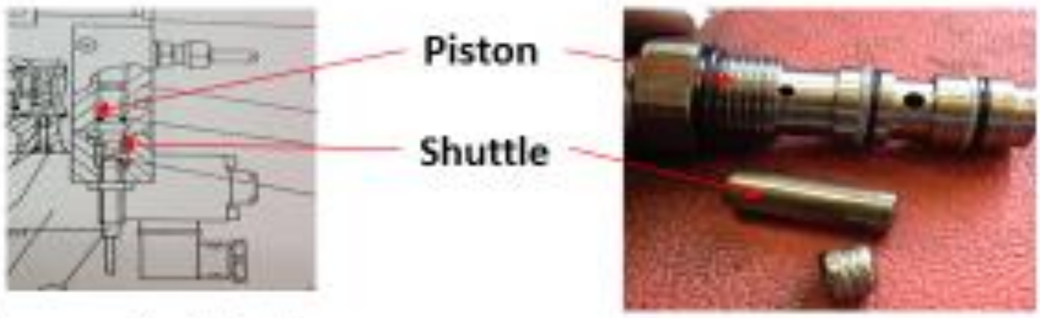
If you have to use the ‘WWLBA’ structure this should be included and explained (WWBLA - Why Why Because Logical Analysis is used to list a set of data required which are logical based on the previous steps, it may involve an experiment to collect further data)

Response
Not used as solution has been found

Question 3.3: Were you able to solve the problem following this step in the process?	Yes	No
	☐	☐

Data required/(explanation)
The root cause of the problem should be detailed and a direct cause and effect link between the initial problem and the root cause should be shown and explained (This question will detail the root cause and the link to initial problem)
Response
See next section

Data required
The solution should be explained and it should be implemented
Response
On inspection the ram seals and light guards were found to be in good order, this left the ram support valve to be the likely cause. The photograph below shows the investigation and solution.



Ram support valve drawing

On closer examination of the old valve I found that the shuttle housing inside the piston had broken, this would cause the shuttle to stick reducing oil flow to the ram and slowing the press down.

As part of the solution valve that was at fault was swapped from one press to the other and the problem moved from one press to the other. Thus, proving the solution.

Data required

It should be possible to compare the before and after process for the problem and explain the benefits in full to your company.

Response

The benefits of this project was a reduction in clipping times from 1:31 minutes to 0:51 minutes which provides an extra capacity to clip of 52000 karabiners each month.

Data required

You should include any other information you feel is relevant including how this method compares to other problem solving methods you have used in your past.

Response

As Manufacturing Manager in an engineering company I face various problems daily, I have been working with Jonathan, during this time I gained knowledge and experience by using various tools including 5W & 1H to solve current production problems. Jonathan's research into problem solving and his teaching of Six Sigma is of great interest to me.

Appendix4 – paper from 2012 – presented by Jonathan Smyth-Renshaw at ENBIS 11 conference – Coimbra Portugal 4-8 September 2011

Exploring the fundamentals of Root Cause Analysis: Are we are asking the right questions in defining the problem?

I Reid and J Smyth-Renshaw
University of Liverpool, UK

Abstract

Purpose – The purpose of this paper is to explore the dynamics of Root Cause Analysis in the context of six sigma and the applicability of the "5W+1H' (What, Why, When Where, Who, How)" technique which is used by many managers in understanding a problem in order to define the root cause.

Design/methodology/approach – The research integrates principles of a traditional literature review with a reflective inquiry of a practitioner.

Findings – The "5W+1H'" methodology is insufficient in identifying the root cause, due to the variations triggered by asking the question 'why'. The paper demonstrates that some extraordinary RCA was achieved by redefining the approach of the 5W+1H' methodology, as catastrophic failures were often the result of misinterpreting the 'why' question. Consequently, the paper identifies a new domain that can be added to traditional RCA and Six Sigma projects.

Research limitations/implications – The study does not address specific ways to simulate those RCA scenarios and problem solving initiatives. Future research is therefore needed in this area.

Originality/value – The paper explores an alternative perspective to the problem definition in RCA. It provides a specific example and suggestions to help practitioners avoid expensive contingency plans, while conducting investigations to RCA using the refined 4W+1H'approach. By questioning in the principles of RCA though a process reflective inquiry, benefits both practitioners and academics.

Keywords: Root Cause Analysis, Process improvement, Six Sigma; Problem solving; Case study

Article Classification: Conceptual paper

1. Introduction:

In today's climate companies need to be able to cope with internal capabilities in order to respond to the characteristics that may affect their ability to deliver a reliably and cost effective product or service. Throughout the world of manufacturing, companies appear to make the same mistakes continuously in the processes of product development and manufacturing production. Companies therefore are in search of rapid approaches that respond to such issues without compromising both product, process and service quality. In such circumstances of failure, organisations naturally adopt investigations such as Failure Modes and Effects Analysis (FMEA) or Root Cause Analysis (RCA). FMEA is shown to be an important tool for improving product quality and on time delivery performance (Crichton 2007), (Kumar and Schmitz 2010), whilst RCA ascertains the source of the problem and recommend corrective actions as remedial actions when faced with manufacturing problems (Pylipow and Royall, 2001). The practice of RCA, which is the theme of this paper, is focused on the belief of such problems are best solved by attempting to correct or eliminate root causes, as opposed to merely addressing the immediately obvious symptoms. There are a number of problem solving tools available in order to maintain economic, robust and speed of delivery approach, which will enhance the ability to deliver quality product. Such problem solving tools are quite similar with special pros and cons of each. In such reoccurring incidents could have been avoided by adhering to just a few fundamental RCA rules, in order to reduce the likelihood of these pitfalls (Sims, 2011). Rooney and Vanden Heuvel (2004) stated that the key for effective problem prevention is to know why the problem occurs. This is because the reoccurrence of the problem can be prevented only through the elimination of its causes (Lehtinen et al 2011).

This paper questions one such RCA technique in order to ascertain the root cause of the problem. More often than not practitioners tend to use either 5Why strategy or the 5W+1H (who- when- where- why- what- how) methodology in order to determine the root cause. By asking the 5 whys question involves looking at any problem and asking strategy: "Why?" and "What caused this problem?" However the 'why' question may distort the response and recommended course of action may distort the true course of action due to the varying possible scenarios of past experiences (Murugaiah 2010). This research aims to develop a framework that removes the focuses on understanding the problem without automatically asking the question 'why' in order to identify the root cause of a problem or defect. The environment of the research was carried out context of defining the root cause analysis methods in a manufacturer context.

2. The focus on Failure

Due to rapidly changing technology and business environments, a company cannot only focus on its products and markets; it must also pay attention to organisational capability. The capability of an organisation generates differentiations from their competitors and is difficult to imitate (Antony, 2006). The organisational capability can be realised through a series of actions and processes that are based on organisational strategic objectives. The performance of these processes markedly influences an organisation's achievements, and customer and stakeholder desires. Consequently, controlling and improving processes continuously is an issue critical to enhancing organisational capability (Stewart & Spencer, 2006). Numerous process improvement methodologies have been widely adopted by various industries, such as 5S, ISO 9000, total quality management (TQM) and lean production, such as Ford's 8D method. Such process improvement techniques can be characterised as the implementation of deliberate changes in the way of doing business to attain improvements in operational excellence, output quality and business performance (Liu, 2006). A comprehensive process improvement methodology should provide a systematic and logical structure that supports factorisation and branching of important factors. In a broad perspective, a process improvement methodology must be able to promote and accommodate all factors directly or indirectly influencing process performance using various techniques, such as project requirement preparation, technical competence, resource configuration and change management. The improvement process should utilise tangible and intangible information to track problem root causes, improve or eliminate the root causes, and monitor and sustain improvement.

2.1 Process Improvement Initiatives

The international ISO 9000 quality standard is a widely accepted definition of the basic characteristics of an effective quality management system (Lin &Wu, 2005; Quazi, Hong & Meng, 2002). The standard establishes and produces an effective quality system of an organization using specific documentation and certification processes. Total quality management is a customer- oriented approach that uses statistical techniques, follows the plan-do-check-act (PDCA) scheme, implements measures and continues improving procedures in order to improve product quality (Rounce, 1998). Particularly, TQM focuses on satisfying customer needs, identifying problems, building commitment and encouraging open decision-making among employees.

2.1.1 Ford's 8D Method

The 8D-method has its historical roots in the quality standard “Corrective Action and Disposition System for Nonconforming Material”, issued by the US military. Introduced in 1974, the 8D method describes a cost efficient plan of action to handle and dispose of non-conforming material. The main goal was the identification of errors, the root cause analysis, the limitation of waste, the prevention of fault reoccurrence, cost reduction in production and a general raise in quality. Problems cannot be solved without definition of the root causes. This process for defining the root causes takes several steps:

- Brainstorming possible causes
- Converting possible causes into most likely causes
- Verified Root Causes

Tools and techniques utilized in 8D to define root causes and their possible solutions are as follows:

- Problem Statement (What is wrong with what?)
- 5 Why technique
- Is and Is Not
- Difference and Change Analysis
- Fishbone/Cause and Effects
- Active and Passive Verification

2.1.2 Six Sigma

Six Sigma initiatives were developed more recently than other approaches within the realms of TQM (Aboelmaged 2009). Six Sigma is a business improvement strategy that aims to identify and eliminate the rate of defects or mistakes in business processes by focusing on outputs that are of critical importance to customers (Snee, 2000) (Ayad 2010). Therefore, we are adopting the six sigma defined by Linderman et al., *(2003)* as:

> *“an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in the customer defined defect rates”*

Six sigma is a highly disciplined and statistic-based scheme for removing defects from products and redundancies from processes (Brue & Launsbry, 2003). Six sigma differs from other improvement programmes in its ‘top-down’ approach and rigorous methodology that demands detailed analysis, fact-based decisions and an effective control plan that ensures ongoing control of a process (Kwak & Anbari, 2006). Although Six Sigma was typically first implemented to improve manufacturing processes, the method can also be utilised in other business processes, such as product design, customer service and supply chain management (Lee et al (2009). Several companies, including Motorola, General Electric (GE), Honeywell, Bombardier and Sony have reported significant benefits from Six Sigma initiatives (Antony & Banuelas, 2001). As a management philosophy, Six Sigma permeates an organization’s culture through comprehensive processes, methods and practices toward continuous improvement and customer satisfaction (Douglas and Erwin, 2000; De Koning and De Mast, 2006). Six sigma therefore permeates an organisation’s culture through comprehensive processes, methods and practices toward continuous improvement and customer satisfaction (Douglas and Erwin, 2000; De Koning and de Mast, 2006).

Six Sigma well-structured methodology of: define, measure, analyse, improve and control (DMAIC) programme, for reducing process variability, improving products and service quality, decreasing costs, eliminating process waste and enhancing profitability and customer satisfaction via effective application of statistical approaches (Coronado & Antony, 2002). Six sigma is an organised process of applying seven tools of problem solving, however, despite the pervasiveness of Six Sigma program implementations, there is increasing concern about variety of analysis methods used to identify the root cause. Six sigma shifts the emphasis from fixing defective products to making perfect products and focuses on reducing the number of opportunities that could result in defects (Antony and Bañuelas, 2001). The focus therefore draws away from the traditional Six Sigma approach and refocuses on the identifying the root cause and definition of the problem.

3. Exploring the 'problem definition'

Product development is a complex exercise where design, materials, manufacturing process operating procedures and sensor location are developed simultaneously for a new product. As experience is gained, process monitoring and control systems are optimized for efficient and reliable product production, thus assuring product quality by the design of the process. Over the past 50 years, the manufacturing companies have spawned many well-known strategies in order to provide the logical steps of RCA within many manufacturing organisations. The pursuit of these quality practices can neutralise the potential negative impacts of manufacturing difficulties and significantly improve product quality and manufacturing performance. The practice of RCA is predicated on the belief that problems are best solved by attempting to correct or eliminate root causes, as opposed to merely addressing the immediately obvious symptoms. By directing corrective measures at root causes, it is hoped that the likelihood of problem recurrence will be minimised. After the identification of the failure, it needed to identify the root causes, take remedial action and perform Kaizen to prevent the further loss occurrence. Different tools and techniques are available for loss analysis. Table 1 presents four such RCA techniques applicable in a total preventative maintenance programmes (TPM) Ahmed et al (2010).

(Table 1 RCA Techniques)

Having an appropriate traceability in place is critical to managing the cause of the breakdown. Ability to track down the root cause with a process has always been important for manufacturers, but in the event of a component failure or process non-conformance. This process for defining the root causes centres around four key steps (Xiaomeng *et al*, 2010):

1. Data collection,
2. Causal factor charting (to find a causal factor),
3. Root cause identification (identify root cause for each causal factor),
4. Recommendation generation and implementation

Browne and Keeley (2004) identified that the traditional 5 Whys approach was insufficient as a tool to identify root cause of problems or process. Limiting the questioning to "why" under any situation deprives the researcher from a wealth of potentially related information that can be acquired by asking more questions (2004, p. 13):

9) What are the issues and the conclusions?
10) What are the reasons?
11) Which words or phrases are ambiguous?
12) What are the value conflicts or assumptions?
13) What are the descriptive assumptions?
14) Are there any fallacies in the reasoning?
15) How good is the evidence?
16) Are there rival causes?

For this reason, this questions the tradition RCA approaches such as the 5Whys, but also the procedure of RCA in order to ascertain the origins of the problem. RCA is ''a process designed for use in investigating and categorising the root cause of events with safety, health, environmental, quality, reliability and production impacts'' (Rooney and Heuvel 2004). It helps identify what, how and why something happened and facilitates prevention and recurrence. RCA is expected to help improve ontology based product design continuously. The research aim is to determine if the 'why' question in RCA distort the true course of action due to the varying possible scenarios of individual's personal experiences?' One reason why the number Six Sigma projects fail is because rationale in the RCA is lacking. By redefining the 5W+1H' (What, When Where, Who, Why, and How) format is considered with the sole purpose which consists of 4W + 1H without asking the question 'Why'. The next section presents the concept in terms of a stepwise approach to defining the root cause on of the problem.

3. Proposal: RCA-5W&1H concept

The purpose of this research is to develop an effective implementation model which consists of 4W + 1H without asking the question Why. This was done using a framework similar to that of a Fishbone diagram (Kelleher, 1995), presented in Fig. 1. The 5W+1H' model uses the theory that WWBLA = Why Why Because Logical Analysis with the overall 5W+1H' steps below. The Fishbone diagram helps to visualize and convey the important relationships between the seemingly 5W & 1H elements.

(Figure 1 RCA-5W+1H Fishbone)

By knowing and controlling *Why*, variability in *root cause* is reduced. Controlling variation in the supply chain, whether common cause or special cause, is the key to consistent, defect-free products and processes delivered to consumers. seven basic quality control tools and is used for the representation of the major problems in a process. Using the DMAIC quality management approach for the purpose of this study, the 'Define' step will outline the current consumer product recall problem definition.

3.1 Worked Example

This section details the proposed method 5W & 1H and uses an example to demonstrates the method, the two photographs below shows a situation of a small vehicle in the water. The problem to solve is why is the vehicle in the water as depicted in in figure 2-'The dilemma'.

(Figure 2- 'The dilemma')

A traditional RCA approach which is often used in problem solving, 8D and Six Sigma is the creation of an appropriate team of people, brainstorm the problem and collect the results on a cause and effect diagram. As this is likely to lead to an extensive list the team would undertake some form of ranking on the most likely causes, possibly in the form of a RCA Ranking Matrix and then the use of the 5 why method to determine possible root causes. Given the dynamics of any team there is a strong likelihood of Groupthink, a phase used by Janis (1972) in which group pressure leads to shortfall in 'mental efficiency, reality testing, and moral judgment'.

For the example given, the leading member of the team could state the driver of the car, driving at night, unskilled driver, under the influence of alcohol and reversed into the water. Whereas, following an investigation the true root cause was a fault handbrake due to lack of service on the vehicle. The RCA-the 5W&1H concept aims to address all the issues which occur with the traditional problem solving approach and avoid the danger of Groupthink, however, the latter issue will not be discussed in detail. If a problem occurs, that is any problem; the level of prior knowledge about the problem will influence the ability to solve the problem. The proposed approach is broken into three levels and the selection of the problem solving team will determine which level is needed to solve the problem. All the levels start with the 5W & 1H.

(Figure 3- The wrong course of action)

The 5W & 1H procedure:

What – what product/service? The description of the product or service which has experienced the problem, if a number of products are using a common process and only one is experiencing a problem, and then the root cause could be the design of the product. It is unlikely that for a service problem this question would yield any information other than the name of the process. In the example of the van in the water the 'what' question does not help and therefore the root cause is not to be found in asking this question.

Who – This question is aimed at determining the people who are present at the time of the problem. In the example of the van this question is important, if the driver was present and saw the van enter the water and said 'I forgot to put the handbrake on' the problem is trivial and solved.

When – This question is concerning the timing of the problem, further to this it is possible to examine possible trends in the problem occurrence. If a problem has a trend for example the problem occurs every Monday at 11am this is very important in the problem solving process. In the example of the van this question is important, if the van entered the water during the night it is unlikely it would have been seen but heard. However, entry during the day it is likely that the van would have been seen.

Where in the process – This question is concerned with the step in the process 'Where' the problem is seen. It is important to understand where in the product/service life cycle or process the problem has occurred, this is likely to involve mapping the process to answer this question. In the example of the van this question would involve trying to understand the time frame from the van being found in the water back in time to establish the root cause of the problem. For example, the time of parking and the last service on the brakes.

Where on the product – This is the position on the product 'Where' the problem is seen. If the problem is only seen in one position then the root cause is likely to be easier to determine that a product with multiply problems are seen in various positions across the product. In the example of the van the 'where on the product' question does not help and therefore the root cause is not to be found in asking this question.

How – is the deviation from target? The product or service should have a standard target condition which is the ideal condition. This target could be known as perfect quality. The aim of this question is to describe the deviation from this target. In the example of the van the deviation from target is the van is in the water and it should be on the side of the harbour.

The aim is to have a clear problem statement using the 5W & 1H statements. The deviation from target (How) is seen (When) by (Who) on product/service (What) in position (Where) and in the location (Where). For the example, the van is in the water at 10am as seen by the driver who failed to apply the handbrake, which could be disclosed as trivial. The example of the van could have been, the van is in the water, nobody saw the van enter the water it happened between 11pm and 6am when the vehicle was found by someone walking their dog. This would be considered not trivial, and highlights the fact that with many gaps in diagnosing the problem. In the case of a problem where the knowledge has gaps it is often helpful to ask 'how does it work?' Again this linked back to prior knowledge of the problem area. This is detailed below.

4 Methodology: Case study Approach

According to Yin (2008) there are three reasons why a case study research methodology is appropriate for this study. The case study approach is preferred when a real world event is examined and since many companies are actively engaged in implementing Six Sigma practices, it is a natural way investigate the scenarios and how the projects evolve. According to Stake (2000), real world studies are valuable for refining theory and suggesting complexities for further investigation. Chakravorty and Hales (2008) also emphasize that the need for real world based research enables managers on their working practice to into robust decision making. Our case study approach by reflective inquiry is appropriate because the approach makes use of variety of evidence in terms of assessing the scenario, in terms of pursuing documents, archival records, interviews, and direct observation. Our case study was carried out with two first tier automotive manufacturers who produce components for a number of prestigious models.

4.2. Data collection

Multiple sources of evidence were used to validate data. Yin (2008) identifies six major sources of evidence. We employed, qualitative data were collected in an observation mode involving reflective inquiry as the researcher was involved with Six Sigma training within the organization, it was also possible to collect data in a participant-observation mode. Additional quantitative data was collected during the diagnosis of the quality issues. These results provided clues to determine the reasons for deeper understanding of RCA were not occurring in the Six Sigma projects. During the study the researcher kept a research log that documented each problem encountered during the implementation, in addition to the thoughts and insights gained during the identification and elimination of failures or errors in manufacturing processes. In the study, we collected data specifically on the implementation and use of Six Sigma. In this study, the unit of analysis was the operational/department level where Six Sigma was designed to be used. Each RCA project was coordinated by the researcher and reviewed in terms of refining the RCA-5W&1H concept.

4.3 Limitation of case study approach

The limitations of case study was that, the conclusions from a single study may have limited generalizability, and therefore, contributing little to developing or informing a theory. Other researchers are encouraged to test these findings by conducting further research a multiple cases.

5. Description of the Method

5.1 Defining the problem-How does it work?

Due to the complexity of problems within complex services or products it is often useful to try to describe how a product or service works in its ideal condition. For a product this would involve a breakdown of the assembly and its component parts to examine the function and fit of the parts. For a service, process mapping as used to answer the 'how does it work?' question but this is same as 'Where' in the process question would be required. Following this structure of questions and fishbone structure can be used but not with the traditional 4M headings – man machine material method but using the 5W and 1H headings as shown below. This approach expands the fishbone structure as man is in who and machine material method are all the heading where the target now is to have one actual root cause on the fishbone structure, but the structure can be used to highlight the missing data, as depicted in Figure 4. The conceptual framework will determine the current baseline and address what data is currently collected regarding recalls of consumer products. The 'Why' question will review an example of how a current state can be scrutinised using a fault tree approach to get to root cause, and how to verify the cause-and-effect relationships, cost implications and gap elimination techniques. During the 'Improve' stage, recommendations will be made as to avoiding recalls in the future. And finally, during the 'Control' stage ideas on sustaining positive results will be made. In this study, the Fishbone diagram to represent the 5W & 1H methodology as the foundation to the root cause analysis.

(Figure 4. The initial conceptual framework)

Another alternative could be listing the causes against the 5W & 1H headings. The ideal target now is to have one actual root cause on the fishbone structure, or failing this a root cause were the 5 why method can be used to get to a root cause which can be undertaken to remove the root cause. This is shown in the Figure 5 below.

(Figure 5. The conceptual framework 2)

In the example of the van, why did the driver not put the hand brake on? Is an example were asking why is sensible as the root cause chain has been determined and asking why only brings further clarification and understanding to the problem. Therefore, this minimises the likelihood that the problem reoccurrences.

The structure can be used to highlight the missing data against each W. This approach introduces a further step using a technique called WWBLA, that is, why why because logical analysis. Given that in the previous steps data has been collected to try to understand the 5W & 1H and also the 'How does it work?' questions. Having not asked why, the understanding of the problem is all fact based but the root cause is not determined, so the WWBLA technique allows logical causes to be listed and the why why technique to be used to obtain an action. This action will involve further data collection to verify whether the logical cause is a 'true' root cause. This structure is shown in the Figure 6.

(Figure 6. The 5W & 1H –WWBLA Concept)

In the example of the van, the van is in the water, nobody saw the van enter the water it happened between 11pm and 6am when the van was found by someone walking their dog. Not trivial with many gaps in the knowledge about the problem. The WWBLA technique could be used to determine the root cause. For example, one logical cause could be the handbrake has not been engaged. This could be proved or not once the van is removed from the water.

With this structure of problem solving it is also true that the true root cause may not determined as to recreate the problem conditions is not possible, for example, the van in the water with no witnesses. However, the structure of 5W & 1H, how does it work?, 5 why (if necessary) and WWBLA is all fact based problem solving and therefore the conclusion from an unsolvable problem will be logical findings but a none provable root cause with a probability of likelihood.

5.1 Case Study –An Automotive Manufacturer

Company X is a multinational automotive manufacture that supplies automotive components worldwide. The problem experienced by a number of customers was focused in the North America. If the problem occurred, it resulted in a sealed component blowing open and the customer hears a loud noise from the area of the engine, as a result the The vehicle automatically stops working. Typically, the failure occurs after a low to mid mileage. On a number of failures by customer's resulted in them contacting the dealer from whom they purchased the vehicle, as a result the dealer contacted the OEM who then initiated a RCA investigation within the complexities of the supply chain. It was at this point the researcher was involved in the investigation. The population of vehicle under the investigation was 835. The researcher was involved identified patterns and common themes by analyzing the experiences of themselves and other participants. The existing method used was the 8D method as developed by the Ford Motor Company. However, As this problem occurred there was an opportunity to use the 5W & 1H method alongside the traditional problem solving method of brainstorming root causes. In this case the supplier had brainstormed the possible root causes and had a list of 46 possible root causes. At this point the problem was redefined using the 5W & 1H method. This is detailed below.

<u>How – deviation from target</u>

10 vehicles from the population of 835 have failed, these components have been analysed and all have the same failure mode. Therefore, the (How) deviation from target was very clear, and explained earlier the sealed component had blown open at the junctions of the two sub-component parts. These parts were sealed with a mechanical process to achieve a pressured seal.

<u>Where on the product is the problem seen</u>

As described in the How question the failure was seen in the same position on the product. This was very important as it pointed the problem solver to the fact that the root cause for the problem was very likely to do one issue or a combination of root causes but all operating in the same configuration each time.

<u>Where in the process is the problem seen</u>

A detailed process map was produced step by step from the point of failure for each of the 10 failures back to the Tier 1 supplier network. During this process, a problem was seen with the pipe work connectors to the component in the OEM, put simply, the inlet and outlet connectors from the vehicle subsystem to the failed component could be mixed. Further analysis of the process determined that the location of the problem in the country showed no pattern. Therefore, the supplier of the failed component started to become excited as the likely root cause was not a supplier issue. It should be noted that within the automotive sector it is common for a supplier to accept the blame for their component failure and the resulting financial penalties.

The misplacement of the inlet and outlet of the connector had not been considered in the vehicle FMEA (Failure Mode and Effect Analysis). The supplier agreed to undertaken an experiment to assess the outcome of the misconnection of the pipe work.

Who

The assembly of each component from the tier 1 supplier was traced and this revealed no pattern i.e. not all assembled by the same operator. As detailed previously, the review of the OEM process highlighted a problem in the assembly process it was observed that it was possible for the outlet and inlet pipes to become mixed and fitted incorrectly. Again the connectors were fitted by various operators and not one 'untrained' operator from one shift. The failed components were seen to be randomly spread throughout the 835 vehicles.

When

The failure was seen in a random pattern but early in the vehicles life. The trend was discrete as 10 from 835 vehicles had the failure. Having completed the 5W and 1H a new problem statement could be written.

New problem statement

The tier 1 supplied component has randomly failed across the country in a small quantity of vehicles; observation of the process shows a problem with the fitting process in the OEM process. Further analysis was recreated by fixing the inlet and outlet pipes incorrectly and the failure did occur as seen in the field.

The tier 1 supplied component has randomly failed across the country in a small quantity of vehicles; observation of the OEM process shows a problem with the fitting process for the inlet and outlet pipes and experimental trials have recreated the failure mode seen in the field.

The consequences of how the 5W&1H technique generated one possible root cause and not the 46 possible root causes the traditional method had generated. To complete, the case study the solution was a Poka-Yoke method, Poka-Yoke (Fisher 1999), is a technique for avoiding simple human error at work, was introduced to the OEM assembly process. This means it was impossible the mix the inlet and outlet pipes. Proof that the action had worked was seen in the next 1024 vehicles for which no further problems were observed, at which point monitoring was stopped.

The challenge with 5W&1H technique far more complex because while focusing RCA, by not understanding the process or product primary function may inflict serious implications to resolving the RCA. It is critical for the 5W&1H methodology to understand and incorporate the problem statement. The intention is neither to ignore life experiences and personal knowledge that worked nor to allow them to dictate the approach to defining the problem; on the contrary, the intention is to produce a balancing act towards defining the RCA and appropriate course of action within such Six Sigma projects. Following on from Armin (2010) critical thinking is core to RCA and other business process reengineering initiatives. RCA practitioners are invited to reflect in action, develop and grow a personal theoretical and practical repertoire of problem definition, and use the principles of RCA and 5W&1H while understanding the context of problem and basic principles of the process or product which has failed prior to drawing the possible conclusions, which the Why question has always influenced the course of action. For practitioners, it is critical aspect to the 5W&1H is absorbing the deviation from target (How) is seen (When) by (Who) on product/service (What) in position (Where) and in the location (Where).

6 Conclusion

The 5W&1H approach, and its methods including RCA, has been applied to reduce the deviation from target as a problem investigated. However the adoption of the fishbone structured Six Sigma processes into RCA platform has room for improvement. While recognising the need for improvements in RCA, some researchers suggested improving it using different technical philosophies. A main area of improvement, however, is in the integration of the principles of critical thinking into the process of Six Sigma (Armin, 2010).

This paper proposes that the 5W & 1H method can be used for problem solving and an example is given to demonstrate the method. The method is totally data driven and makes the user collect data to define the problem prior to any root cause analysis. If data is missing then further data collection will be required and this may include the need to experiment to obtain a deeper understanding of the problem. The 5W & 1H method is aimed at anyone undertaking problem solving in any situation. This paper demonstrated that RCA methodologies such as 5W&1H to identifying root causes of defects, business process variations, and other business problems are hampered by the why question, As those 'why' answers could incur the wrong cause of action such as supplying an inadequate crane to recover the vehicle from the water. This scenario could have been prevented through the absorbing the deviation from target (How) is seen (When) by (Who) on product/service (What) in position (Where) and in the location (Where).

Furthermore, RCA has the capacity to explore the context of situations, and provides a broad platform for understanding patterns, consequences, and risks. This may explain the mystery behind the wide variations between successes and failures of such Six Sigma initiatives across industries as employees trained on Six Sigma and Six Sigma consultants vary greatly in their problem solving capacities and life-experiences as witnessed by the researcher reflective inquiry.

Reference:

Aboelmaged M.G., (2009) Six Sigma quality: a structured review and implications for future research', Quality and Reliability Engineering International, Vol. 27 Issue 3

Ahmed T., Ali S.M Allama M.M., Parvez, M.S. (2010) A Total Productive Maintenance (TPM) Approach to Improve Production Efficiency and Development of Loss Structure in a Pharmaceutical Industry', Global Journal of Management and Business Research Vol. 10 Issue 2

Anthony, J. and Banuelas, R. (2002), "Key ingredients for the effective implementation of Six Sigma program", Measuring Business Excellence, Vol. 6 No. 4, pp. 20-7.

Amine, A., (2010) "Critical thinking and business process improvement", Journal of Management Development, Vol. 29 Iss: 6, pp.556 - 564

Antony, J. (2006). Six Sigma for service processes. Business Process Management Journal, 12(2), 234–248

Bañuelas, R., Antony, J., & Brace, M. (2005). An application of Six Sigma to reduce waste. Quality and Reliability Engineering International, 21(6), 553–570

Brue, G., & Launsbry, R. (2003). Design for six sigma. New York: McGraw-Hill.

Coronado, R.B., & Antony, J. (2002). Critical success factors for the successful implementation of Six Sigma projects in organizations. The TQM Magazine, 14(2), 92–99.

Chakravorty SS., and Hales, DN., (2008), 'The evolution of manufacturing cells: an action research study'. European Journal of Operational Research, 188 (2008), pp. 153–168.

Crichton, K., 2007. Total recall – traceability of products. *Manufacturers Monthly*, October, 64–65.

De Koning, H., De Mast, J., Does, R., Vermaat, T. and Simons, S. (2008b), “Generic lean Six Sigma project definitions in financial services”, The Quality Management Journal, Vol. 15 No. 4,pp. 32-45.

Douglas, P.C. and Erwin, J. (2000), “Six Sigma’s focus on total customer satisfaction”, Journal for Quality and Participation, Vol. 23 No. 2, pp. 45-9.

Michael Fisher, (1999) "Process improvement by poka-yoke", Work Study, Vol. 48 Iss: 7, pp.264 – 266

Irving J., L. (1972). Victims of Groupthink, New York : Houghton Mifflin.

Karim, MA, Smith, AJR and Halgamuge, S. 2008. Empirical relationships between some manufacturing practices and performance. *International Journal of Production Research*, 46(13): 3583–3613.

Kelleher, 1995, K. Kelleher, Cause-and-effect diagrams: Plain and simple, Joiner Associates Incorporated, WI (1995).

Kwak, YH., & Anbari, F.T. (2006). Benefits, obstacles, and future of six sigma approach. Technovation, 26(5–6), 708–715.

Kumar, S., Schmitz, S., (2011) ‘Managing recalls in a consumer product supply chain - root cause analysis and measures to mitigate risks. International Journal of Production Research, Vol. 49 Issue 1, p235-253

Lee, KL., Wei, CC., Lee, HH., (2009), ‘Reducing exposed copper on annular rings in a PCB factory through implementation of a Six Sigma project’, Total Quality Management Vol. 20, No. 8, August 2009, 863–876

Lehtinen T.O.A., Mäntylä M.K., Vanhanen, J., (2011), ‘Development and evaluation of a lightweight root cause analysis method (ARCA method) – Field studies at four software companies’, In Special Section on Mutation Testing, Information and Software Technology Vol, 53, Issue 10 Pages 1045-1061

Lin, C., & Wu, C. (2005). A knowledge creation model for ISO 9001: 2000. Total Quality Management & Business Excellence, 16(5), 657–670.

Linderman, K., Schroeder, R., Zaheer, S. and Choo, A. (2003), “Six Sigma: a goal – theoretic perspective”, Journal of Operations Management, Vol. 21 No. 2, pp. 193-203.

Liu, E.W. (2006). Clinical research the Six Sigma way. Journal of the Association for Laboratory Automation, 11(1), 42–49

Murugaiah, U., Jebaraj, S., Benjamin, Marathamuthu, M., Muthaiyah S., (2010) ‘Scrap loss reduction using the 5-whys analysis’, International Journal of Quality & Reliability Management Volume: 27 Issue: 5

Quazi, H.A., Hong, C.W., & Meng, C.T. (2002). Impact of ISO 9000 certification on quality management practices: A comparative study. Total Quality Management, 13(1), 53–67.

Pylipow, P.E., Royall, W.E. (2001), "Root cause analysis in a world-class manufacturing operation", Quality, Vol. 40 No.10, pp.66-70.

Rooney, J.J. and Heuvel, L.N.V., (2004). Root cause analysis for beginners. American Society for Quality, Quality Progress, 37 (7), 45–53.

Rounce, G. (1998). Quality, waste and cost considerations in architectural building design management. International Journal of Project Management, 16(2), 123–127.

Shainin,R., (1993) Strategies for technical problem solving. Quality Engineering, 5 (1993), pp. 433–448.

Sims, D., (2011). Industrial Engineer: IE, Mar2011, Vol. 43 Issue 3, p37-40, 4p

Snee, R (2011), ‘Understanding Formulation Systems-A Six Sigma Approach’, Quality Engineering, Vol. 23 Issue 3, p278-286

Stake, R.E., Case studies, N.K. Denzin, Y.S. Lincoln, Editors , Handbook of Qualitative Research, (second ed), Sage Publications, Thousand Oaks, CA (2000), pp. 435–454.

Stewart, R.A., & Spencer, C.A. (2006). Six-Sigma as a strategy for process improvement on construction projects: a case study. Construction Management and Economics, 24(April), 339–349.

Xiaomeng C., Terpenny, J., Koelling P.,(2010) ‘Reducing errors in the **development**, maintenance and utilisation of ontologies’ International Journal of Computer Integrated Manufacturing, Apr2010, Vol. 23 Issue 4, p341-352,

Yin, 2008 R.K. Yin, Case Study Research: Design and Methods, Sage Publications, Thousand Oaks, CA (2008).