UNIVERSITY OF KWAZULU-NATAL

AN INTEGRATED DESIGN FOR SIX SIGMA STRATEGY TO A NEW PRODUCT DESIGN IN A GLOBAL RESOURCES COMPANY

by

SANJAY DYMOND

203518439

A dissertation submitted in partial fulfilment of the requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

In the Graduate School of Business

SUPERVISOR: MR ROBIN MARTIN CHALLENOR

2006

DECLARATION

This research has not been previously accepted for any degree and is not being currently submitted in candidature for any degree. I declare that this dissertation contains my own work except where specifically referenced and acknowledged.

Sanjay Dymond - 203518439

Signed: ____________

Date: 1 October 2007

DEDICATION

This dissertation is dedicated to my late mother, father and brother, Mrs JD Dymond, Mr Dymond and Mr K Dymond respectively, to my wife Lucy Dymond and to my sons Liam and Kayem Dymond who all contributed to my success in achieving a master's degree.

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation and thanks to his supervisor Mr Robin Martin Challenor for his invaluable coaching, guidance, supervision, patience and support during the course of my research. Also I would like to extend a special thanks to my wife Lucy and my two sons Liam and Kayem Dymond for their valued support and patience during the phase of this difficult undertaking. Sincere thanks also to the members of the graduate school, especially Christel Haddon and Isabel Kerrin for their valuable assistance, help, input and patience. Subject matter experts, friends, managers and employees of Manganese Metal Company and the BHP Billiton customer sector groups are also acknowledged for their time, assistance and knowledge contribution to this dissertation.

ABSTRACT

This dissertation reports on the research work of a new business improvement methodology called the design for Six Sigma (DFSS) conducted within a global resources company with specific reference to Manganese Metal Company (MMC), a subsidiary of BHP Billiton (BHPB). The aim of this research was by means of a case study, through action research, to investigate, analyse and evaluate the "Define, Measure, Analyse, Design and Verify" (DMADV) model proposed by Picard (2004) with specific reference to a new product design. The study was concerned with identifying the BHPB strategic business reasons, effects and analysing the financial impact of implementing a DFSS project pertaining to a new product design at MMC. The literature review highlighted that DFSS enhances revenue growth, quality and reliability for a new product. The key findings were that DFSS does not exist within MMC and BHPB, the DFSS methodology could improve and enhance the revenue for a new product design at MMC and none of the BHPB customer sector groups are reporting any operating excellence (OE) annualised cost improvement benefits for DFSS projects. The main recommendation emerging from this research is that an integrated DFSS process will enable BHPB to identify critical leverage points for improving the overall financial performance in achieving the FY09 OE objective of $1 billion in annualised cost improvement benefits thus achieving the world class benchmark standard set by General Electric Corporation.

TABLE OF CONTENTS

Chapter 1

INTRODUCTION

1.1. Introduction

This chapter summarises the structure of the dissertation. It outlines a brief history of the company and a review of the research problem with a concise background to the study, motivation, value, problem statement and structure of the research project. It also outlines the objectives and the research methodology.

This research topic examines a new paradigm called the design for Six Sigma (DFSS) methodology using the "Define, Measure, Analyse, Design and Verify (DMADV) model for new products, processes and services design that currently do not exist in a company. The case study in question focuses specifically on a new product design encompassing the DFSS methodology in BHP Billiton with specific reference to Manganese Metal Company.

According to Pyzdek (2003), DFSS is a systematic methodology utilising tools, training and measurements to design new processes, products or services that meet customer expectations at Six Sigma quality levels. According to Picard (2004), Sigma is a statistical concept that represents the amount of variation present in a process relative to customer requirements or specifications. When a process operates at a Six Sigma level, the variation is so small that the resulting products and services are 99,9997% free of defects, i.e. the organisation has set a level of Six Sigma being no more than 3,4 defects per million opportunities (DPMO) as a quality goal for the products and services they provide to its customers.

Chowdhury (2004) states that “the money exists in the design for Six Sigma methodology. If you change a product after it is launched it will cost you 1000 times more than if you made those changes during the design stage”.

The reason to accomplish DFSS is ultimately the gain in financial benefits. It generates shareholder value based on delivering customer value in the market place. Products developed under this discipline and rigor of a DFSS enabled product development process will generate measurable value against quantitative business goals and customer requirements. DFSS helps fulfill the voice of the business by fulfilling the voice of the customer. DFSS satisfies the voice of the business by generating profits through new products, processes and services. It satisfies the voice of the customer by generating value through new products, processes and services. It helps organisations to meet these goals by generating a passion and discipline for new products, processes and services development excellence through an active and dynamic leadership (Creveling *et al.*, 2003).

Design for Six Sigma is not just a quality or redesign initiative but also a management philosophy, a way that senior management can develop corporate objectives for customer requirements and financial targets. One of the key deliverables that the proponents of design for Six Sigma argue is whether it will deliver superior financial results and it is this element, which is the key focus of this dissertation. The aim of this dissertation is to assess whether the design for Six Sigma methodology will deliver the bottom line financial benefits for a new product design at MMC and improve the strategic target for the operating excellence earnings before interest and tax (EBIT) annualised improvement benefit of $1 billion for financial year (FY) 2009 at BHPB. According to Anglin (2003), the operating excellence EBIT annualised improvement benefits are defined as the actual financial cost savings for all Six Sigma continuous improvement projects to enhance profitability within BHPB. This dissertation will review the current DFSS methodology and teachings applied in DFSS and how this translates into financial benefits through the execution of the Define, Measure, Analyse, Design and Verify (DMADV) model.

1.2. Research problem

This research problem examines a new paradigm called the design for Six Sigma (DFSS) methodology using the Define, Measure, Analyse, Design and Verify (DMADV) model for a new product design that currently do not exist in Manganese Metal Company. A case study of a DFSS project with specific reference to a new product design is discussed.

1.3. Background to the study

In the new millennium, most organisations are embracing business excellence, operating excellently, adding value, implementing world class manufacturing practices and management of change. Industries from manufacturing to service are witnessing the growth of a strategic continuous improvement concept called the design for Six Sigma. Tools, such as run charts and measurement system analyses that a quality department might normally use for assurance purposes are expanding to all aspects of the business, in part, by way of Six Sigma and the design for Six Sigma. This customer focused concept appears to thrive on process improvement and innovation and it has been touted as a principal source for creating enormous savings and leading business strategy (Harry, 1998; Hoerl, 1998; Pande, *et al.*, 2002). Six Sigma's main objectives are to reduce variation and defects, increase customer satisfaction and increase profits in existing operational and transactional processes (Goh, 2002; Hahn, *et al.*, 1999; Harry, 1998), however, the design for Six Sigma methodology is applied to the design or redesign of new products, processes and services that do not exist to ensure the achievement of high levels of quality before it is developed. BHPB implemented the operational Six Sigma concept in 2001, however, the design for Six Sigma methodology has not been implemented to all its customer sector groups.

Manganese Metal Company (MMC), a subsidiary of Samancor is part of the Carbon Steel Materials customer sector group (CSG) business segment of the BHP Billiton (BHPB) resources company. BHPB is the world's largest diversified resources company. BHPB was created through the Dual Listed Companies (DLC) merger of BHP Limited (now BHP Billiton Limited) and Billiton Plc (now BHP Billiton Plc), which was concluded on 29 June 2001. BHP Billiton Limited and BHP Billiton Plc continue to exist as separate companies but operate on a combined basis as BHP Billiton. The headquarters of BHP Billiton Limited and the global headquarters of the combined BHP Billiton Group are located in Melbourne, Australia. BHP Billiton Plc is located in London, United Kingdom. Both companies have identical board of directors and are run by a unified management team. Shareholders in each company have equivalent economic and voting rights in the BHP Billiton Group as a whole (Internet 1).

BHPB have more than 105 000 employees working in more than 100 operations in more than 25 countries. BHPB occupy industry leader or near industry leader positions in major commodity businesses, including aluminium, energy and metallurgical coal, manganese, copper, ferro-alloys, iron ore and titanium minerals. BHPB also have substantial interests in oil, gas, liquefied natural gas, uranium, nickel, diamonds and silver. BHPB is distinguished from other resource companies by its quality assets; deep inventory of growth projects; customer focused marketing; diversification across countries; commodity markets and the petroleum business (Internet 1).

The central tenet of the BHP Billiton business model is that its diversified portfolio of high quality assets provides more stable cash flows and greater capacity to drive growth than the traditional resource cyclical. As at 30 June 2006 financial year end, BHPB generated turnover of US$39.1 billion, underlying earnings before interest and tax

(EBIT) of US$15.3 billion, attributable profit (excluding exceptional items) of US$10.2 billion and net operating cash flow of US$10.5 billion. As at 17 August 2006, the market capitalisation of BHPB was US$122.5 billion (Internet 1).

1.3.1. Operating Excellence

Operating Excellence (OE) is the brand name of BHP Billiton's preferred business improvement methodology to equip the BHPB employees to generate business improvement cost savings which was implemented in 2001 after the merger. The OE function was focused on increasing shareholder value through creation of knowledge sharing networks in the core operational processes of mine planning, mining, processing, maintenance and logistics through the use of the Six Sigma improvement methodology to address improvement opportunities in the BHPB businesses. Improving the business performance helps BHPB remain competitive and 'stay in the game' (Anglin, 2003). The OE programme broadly covers two areas – Six Sigma and Networks. The programme is supported by an OE functional group which is regionally based in Australia, South Africa and South America (Smith, 2004). OE uses the operational Six Sigma - Define, Measure, Analyse, Improve and Control (DMAIC) model for its business' continuous improvement methodology.

The BHP Billiton's Strategic Plan sets out eight imperatives, one of which is to operate excellently. This imperative challenges the employees to (Internet 2):

- Deliver on benefits equating to 4.4 percent of total costs with an achievement of more than US$1 billion in annualised improvement benefits by the end of FY 2009.
- Increase the EBIT and free cash flow with the aim of achieving a return on capital of more than 15 percent by FY 2009.

OE is the preferred business and process improvement initiative that supports BHPB businesses to operate excellently. It uses and is supported by:

- *Six Sigma improvement methodologies - DMIAC Model.*
- Site based coaches.
- Knowledge sharing Networks and Communities of Practice.
- Online tools and services.

BHP Billiton commenced deploying its Six Sigma programme in 2001 and now has many people working right across the globe on a range of improvement projects using the Six Sigma methodology. The programme has continued to build momentum, with asset sites reporting benefits of more than US$190 million from more than 650 Six Sigma projects. From financial year end 2001 to 2005, the OE activities delivered more than US$600 million in cumulative EBIT annualised improvement benefits. The target for FY 2009 is US$1 billion in cumulative EBIT annualised improvement benefits. In 2005 a decision was taken by the Executive Management Committee to expand the improvement focus within BHPB to include both the core operational processes and the core organisational processes, i.e. to expand the focus from Operating to Business Excellence (BE). In the beginning of

2006, the function of OE was charged with the responsibility to manage the BE programme and accordingly changed its purpose, structure and name to Business Excellence.

1.4. Motivation for the research

The current problem at BHPB is the Six Sigma methodology using the DMAIC model in OE does not support new processes, products or services that do not currently exist. This research examines a new paradigm called the design for Six Sigma (DFSS) methodology using the Define, Measure, Analyse, Design and Verify (DMADV) model for new products, processes and services design in the organisation. A summary of the progress relating to the new product design effort and an analysis of the applicability of some of the DFSS tools demonstrated will be discussed at each stage of the DMADV model. This research was aimed at analysing the functionality of the DFSS tools used during the new product design stage and reporting on the optimised financial benefits. The evaluation will also show the implications of delaying a DFSS project and its impact on earnings before interest and tax (EBIT), net present value (NPV) and the internal rate of return (IRR) for a dynamic new product design project.

The attraction of this research as a topic is due to the lack of DFSS business case research material found relating to new products, processes or services design in the BHPB business improvement process during the literature search.

DFSS topic searches were conducted using the annual company reports, intranet and internet search engines resulted in no examples being found in the_literature search in which the DMADV model was used for new products, processes or services design at BHPB. However, examples were found in other organisations, e.g. General Electric, Motorola, Sony, Caterpillar and Allied Signal.

In order to ascertain whether the DFSS proposal is positive it would be worthwhile to evaluate the DFSS process on a new product design that does not currently exist and the impact it has on the company's operating excellence strategic objectives.

1.5. Value of the project

The value of this research will enable BHPB to implement the DFSS methodology. DFSS could ultimately have a major positive effect on the OE annualised cost improvement benefits for earnings before interest and tax. Most importantly benchmarking of performance will be enhanced based on the fundamental improvement to the financial performance of the BHPB business imperative. Envisaged are a significant number of DFSS projects being completed with sustainable annualised continuous improvement financial benefits. Embedding the DFSS methodology programme in the OE strategic plan, BHPB will deliver on achieving its OE objective, declaring more than US$1 billion in annualised continuous improvement benefits by the end of FY 2009.

On achieving its operating excellence objectives BHPB will be more profitable and gain competitive advantage and will facilitate the accomplishment of its OE goals and it's Charter (Internet 3).

OE vision and Mission

- Vision: "BHP Billiton is simply seen as the best operator in the resources business".
- Mission: "Enabling BHP Billiton businesses to operate excellently".

According to Goodyear (2005) "Six Sigma is a preferred improvement methodology, it aligns very closely with the BHPB strategic drivers of 1) People; 2) Low cost long reserve life operations and 3) Generating and sharing efficiencies as well as the BHPB Value Drivers of Customer Centric Marketing and Innovation. By applying the Six Sigma principles the right projects are selected for the right reasons and improvements are put in place that not only meet but exceed the BHPB customer's expectations - both internal and external, allowing BHPB to Operate Excellently" (Internet 4).

1.6. Problem statement

Implementing DFSS in any organisation is currently expensive with respect to costs of training, development and deployment. However, it is a rigorous and systematic process to enhance new processes, products or services design. Although the DFSS process does not exist at BHPB, it is currently being evaluated to determine whether it is appropriate (suitable and acceptable) for the organisation, taking into account its impact and the benefits on the OE strategic objectives, EBIT, net present value and internal rate of return.

An integrated DFSS approach to a new product design project will benefit EBIT, net present value, internal rate of return and the FY 2009 OE strategic objectives, which are:

- The probable effect of DFSS on a new products financial performance in Manganese Metal Company.
- The effect a delay in implementing a DFSS project could have on EBIT, net present value and internal rate of return of the new product design project at MMC.
- Is there a significant difference in the means for EBIT between the various business improvement methodologies at MMC or not.
- The effect of DFSS on the BHPB FY 2009 OE strategic objectives.

1.7. Objectives

The objective of this dissertation is to identify why the DFSS methodology becomes a priority in the BHPB business improvement plan, to test the applicability and to determine the use of the DFSS methodology for a new product design. To evaluate DFSS for a new product design project and the impact it has on EBIT, net present value and internal rate of return. To evaluate the impact of DFSS on the BHPB's operating excellence strategic objectives.

The focus of the study will be:

- To evaluate the DFSS process and whether it is suitable to achieve the desired end result that is expected for new product design at MMC. An analysis of the impact of using DFSS in a new product design using some of the tools will be carried out and an evaluation of this methodology will be undertaken against the DMADV model.
- To establish the impact of the DFSS process on BHPB's FY 2009 OE objectives and the delay of implementing a DFSS project and its effect on NPV and IRR. Data will be collated for the years 2001 to 2005 for analysis. Comparison of the data will be able to give an indication of the extent to which the company has achieved its OE strategic objectives, the pace of its performance and whether it would successfully achieve its FY 2009 targets and how can DFSS contribute to the bottom line of the FY 2009 targets.

In so doing it is hoped to discover any flaws in the research process so that appropriate recommendations and an action plan can be proposed to management.

1.8. Research methodology

The topical scope of the dissertation will be a comparative case study utilising action research with a specific application to evaluate an organisational management problem. This dissertation will be of an explanatory nature utilising an existing DFSS model to identify how it can enhance organisational financial performance pertaining to a new product design at MMC and the OE strategic objectives at BHPB.

According to Bonoma (1985) in Ghauri and Gronhaug (2002), case research is based on a process model and involves data collection through multiple sources such as verbal reports, personal interviews and observation as primary data sources. In addition, case methods also involve data collection through sources such as financial reports, archives, budgets and operating statements, including market and competition reports. Also data will be collated in the areas of operating excellence, projects, quality and production reports. This will be available from the company's monthly, quarterly and annual reports. This will be secondary data. Selltiz *et al.*, (1976) in Ghauri and Gronhaug (2002) states that this approach relies on the integrative powers of research: the ability to study an organisation with many dimensions and then to draw an integrative interpretation.

It is recognised that a case study approach is often criticised because they can lack statistical validity and become overly generalised. However, since one of the objectives is to produce recommendations to management, a case study approach is considered appropriate, a view supported by Alloway (1977). Case studies are particularly well suited to new research areas for which existing theory seems inadequate. This type of work is highly complementary to incremental theory building from normal science research. The former is useful in early stages of research on a topic when a fresh perspective is needed, while the latter is useful in later stages of knowledge according to Eisenhardt (1989: 548-9) in Ghauri and Gronhaug (2002).

Action research was used as the primary research method for the *design for Six Sigma project dissertation*. The in-depth participation and ability that action research provides (Susman and Evered, 1978; Westbrook, 1994; Coughlan and Coghlan, 2002), gives the researcher the opportunity to identify several factors affecting the decision of choosing DFSS. It also allows the researcher to legitimately intervene in the operational Six Sigma practice in the company to test the applicability of DFSS to deal with the problem of designing new products, processes, services or when the existing process, product or service requires such significant change that an improvement process is inadequate and a redesign is required. Action research differs from other forms of applied research because of its explicit focus on action, in particular promoting change within the organisation according to Marsick and Watkins (1997) in Saunders *et al.*, (2003). As Coghlan and Brannick (2001) in Saunders *et al.*, (2003) note: "the purpose of action research and discourse is just not to describe, understand and explain the world but also to change it."

1.9. Limitations

The following limitations were placed on this study:

- The study was limited to operating excellence at BHPB and more specifically to MMC for a redesign on an existing product using the DFSS methodology in a case study.
- The study was limited to the years 2001 to 2005. It does not apply to the years after 2005 because the DFSS model is

currently not being used and implementation maybe during 2007.

- All the various business improvement projects were segmented into Six Sigma, DFSS, lean Sigma and the replication Six Sigma methodologies at MMC.

1.10. Assumptions

It is assumed that all the data is reliable and valid. It is assumed that the measurement instrument is valid. MMC is a dollar reporting company within the BHPB customer sector group. During the research, it was assumed that $1 equated to R7.25 in foreign exchange.

1.11. Structure of the research

The dissertation consists, besides the introduction, of five additional chapters:

- Chapter one – Introduction. This chapter highlights what this research project intends to accomplish.

- Chapter two – Literature review. This chapter will deal with various concepts in the research areas of design for Six Sigma. The theories and models on DFSS will be discussed. The DMADV model will be used and adapted for the study. A roadmap model will be developed in relation to the DMADV model.

- Chapter three – Research Methodology. Action research was used as the research method for the dissertation.

- Chapter four – The Case for DFSS. A detailed review of the DFSS case study in practice is provided here. The roadmap model developed from the DMADV model will be used as a framework to write the case study. This includes the envisaged DFSS process for the new AMT product design at MMC.

- Chapter five – Results and Discussions. The results obtained through the action research are presented and described here. An evaluation of the information in chapter four against the "DMADV" model chosen in chapter two will be carried out. An indication of what MMC and BHPB has done "well" and what they are "not" doing in order to be successful companies is presented here. The data will be analysed and evaluated to establish the level of financial benefits that have been achieved and to identify any significant trends or factors. A summary of the main findings and principle features of the dissertation is provided.

- Chapter Six – Conclusion and Recommendations. Finally, the dissertation will discuss the conclusions and recommendations to the OE deployment team on how improvements to the financial returns can be achieved by the application of DFSS and some key focus points for future research.

The data presented in this dissertation is only an infinitesimal proportion of the total amount collected for the study.

1.12. Summary

This chapter is a summary of the dissertation that evaluates DFSS and the impact it has on OE at BHPB. The research examines a new paradigm called the design for Six Sigma (DFSS) methodology using the Define, Measure, Analyse, Design and Verify (DMADV) model for a new product design that do not exist in Manganese Metal Company. The reason to do DFSS is ultimately financial. It generates shareholder value based on delivering customer value in the market place. Products developed under this discipline and rigor of a DFSS enabled product development process will generate measurable value against quantitative business goals and customer requirements. DFSS helps fulfill the voice of the business by fulfilling the voice of the customer. DFSS satisfies the voice of the business by generating profits through new products. It satisfies the voice of the customer by generating value through new products. It helps organisations to meet these goals by generating a passion and discipline for product development excellence through active and dynamic leadership (Creveling *et al.*, 2003).

In addition this chapter also outlines the structure, the literature review, DFSS in practice, the research methodology, the results and discussions of DFSS, the conclusions, the recommendations and the limitations of the dissertation.

1.13. Conclusion

In this chapter attention has been given to the orientation with respect to the research. The next chapter focuses on the literature review pertaining to the design for Six Sigma methodology.

Chapter 2

LITERATURE REVIEW

2.1. Introduction

This chapter is concerned with the various literature regarding the issues and discussions concerning the design for Six Sigma methodology. The purpose of the literature review was to summarise the various areas of controversy surrounding the applications of the design for Six Sigma methodologies in industry.

A brief history of the latter terms, followed by a discussion on the definition, tools, types and models of DFSS is provided. A study of the different relationships of DFSS strategies currently being employed and developed in the company is also discussed.

Advocates of DFSS view it not only as a quality initiative but also as a management philosophy, a way that executive management can develop corporate objectives for customer requirements and financial targets. One of the key deliverables that the proponents of DFSS argue is whether it will deliver an improved financial result in a new product design which is a key focus in chapter four.

DFSS is used to develop a new process, product or service at Six Sigma quality levels with the voice of the customer leading the way. DFSS is also used when an existing process, product or service requires such extensive change that incremental improvements will be insufficient and a redesign is required. Pande *et al.*, (2000) and Eckes (2001a) propose that a process or product redesign is suitable when the new process or product will assist an organisation to achieve a strategy objective. DFSS is a structured, disciplined and rigorous approach to Six Sigma design in five phases, namely, define, measure, analyse, design and verify.

2.2. Sigma

In terms of meaning, the lowercase Greek symbol σ (Sigma) is the metric or fundamental statistical concept that denotes a population's standard deviation and is a measure of process variation or dispersion about a mean. It is also defined as the standard deviation of a process in statistical control. According to Picard (2004), Sigma is a statistical concept that represents the amount of variation present in a process relative to customer requirements or specifications. When a process operates at a Six Sigma level, the variation is so small that the resulting products and services are 99,9997% free of defects, i.e. the organisation has set a level of Six Sigma being no more than 3,4 defects per million opportunities (DPMO) as a quality goal for the products and services they provide to its customers.

2.3. Variation

A process can be defined as a series of operations performed to bring about a result. The result can be the delivery of a service or the manufacturing of a product. Variation is the sum total of all the minuscule changes that occur on occasion. Variation is always present at some level. Processing consistency and minimal variation leads to improved quality, reduced costs, higher profits and happier customers (Bertels, 2003).

2.4. Defect rate versus process Sigma

Process Sigma refers to the current capability of a process, i.e. how well the process is performing relative to customer specifications (Picard, 2004). Motorola used the operational Six Sigma improvement methodology to express its quality goal of 3.4 DPMO where a defect opportunity is a process failure that is critical to the customer. Motorola set this goal so that process variability is ±6 standard deviation from the mean (Breyfogle *et al.*, 2001, p. 39). Motorola further assumed that the process was subjected to disturbances that could cause the process mean to shift by as much as 1.5 standard deviation off the target (Montgomery, 2001, p. 23). Factoring a shift of 1.5 standard deviation in the process mean then results in a 3.4 DPMO (Montgomery, 2001, p. 24 and Breyfogle *et al.*, 2001, p. 40).

This goal was far beyond normal quality levels and required very aggressive improvement efforts. For example, 3 Sigma results in a 66,810 DPMO or 93.3% process yield, while Six Sigma is only 3.4 DPMO and 99.99966% process yield (these computations assume a 1.5 standard deviation shift in the process mean). Fig. 2.4.1 shows the graphical relationship of Sigma conversion between DPMO and process Sigma assuming a normal distribution of data. Not all processes should operate at the Six Sigma level. The appropriate level will depend on the strategic importance of the process and the cost of the improvement relative to the benefit.

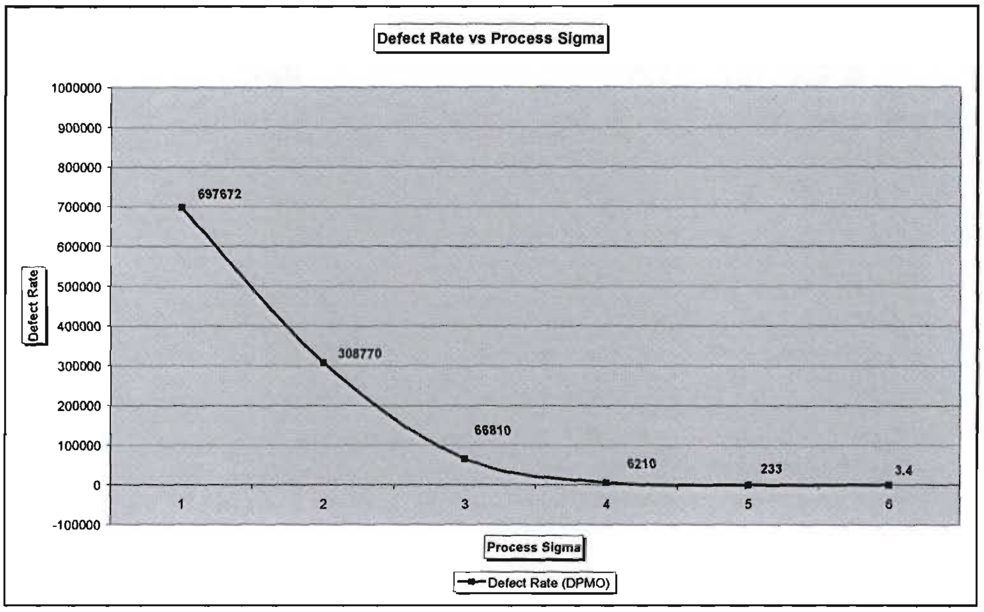

Figure 2.4.1: Relationship between defect rate and process Sigma (Source: Picard, 2004)

If a process is at the two or three Sigma level, it will be relatively easy and cost effective to reach the four Sigma level. However, to reach the five or Six Sigma level will require much more effort and more sophisticated statistical tools. The effort and difficulty increases exponentially as the process Sigma increases. Ultimately, the return on investment for the improvement effort and the strategic importance of the process will determine whether the process should be improved and the appropriate target Sigma level as a goal. Picard (2004) states that it is generally accepted that the DMAIC methodology can shift a Sigma level from 3 Sigma to about 5.0 to 5.5 Sigma. At that point, the rate of return on effort diminishes considerably. For this reason, continued use of the DMAIC methodology may be inadequate. To achieve higher Sigma performance, a process, product or service redesign will be required to ensure the capability of achieving a higher level of performance.

2.5. Design for Six Sigma defined and explained

DFSS is potentially far more effective than DMAIC as its application is in the early stage of new product and process development, yet it has received less attention in the literature.

The term Six Sigma is used to describe a process improvement strategy to meet or exceed customer needs and return money to the corporate bottom line. It is a structured, disciplined and data driven process for improving business performance. At the same time, it is also a measure of process capability that enables to establish how capable a process is of meeting customer requirements and to determine how far a given process deviates from perfection (Bertels, 2003).

The idea of creating Six Sigma products began at Motorola in the 1980s. After reducing labour costs to nearly half of their previous levels and reducing waste by around 65%, Motorola quickly became more competitive as a result of Six Sigma. Other companies began to adopt

Six Sigma philosophies after observing Motorola's success. These early Six Sigma efforts focused on improving manufacturing processes. In the 1990s, it became apparent that in order to produce true Six Sigma products, quality had to be designed into a product starting in its early design stages (Creveling *et. al.*, 2003).

In addition to problem solving, Six Sigma offers a design component, generally known as design for Six Sigma (DFSS) and is used for radical or incremental new service, process or product design and also when an existing service, process or product requires such significant change that an improvement process is inadequate and a redesign is required. As with the problem solving methodology, DFSS builds on earlier design methodologies, such as Juran's quality planning (Juran *et al.*, 1993), but goes further. While DMAIC, the Six Sigma problem solving methodology, for most part focuses on process improvements and cost reductions, DFSS looks toward process or product designs with an objective for optimum revenue growth. DFSS is also used for process or product redesign where improvements can no longer meet customer requirements.

According to Harry and Schroeder (2000), organisations which have adopted the principles and concepts of the Six Sigma improvement methodology have realised that once they have achieved five Sigma quality level (i.e. 233 defects per million opportunities), employing the DMAIC model, the only way to surpass the five Sigma quality level barrier is to redesign their products, processes or services by means of DFSS. Although this affirmation is highly arguable, because of lack of data to support the claim and the absence of assumptions used to formulate it, other authors have tended to support it (Chowdhury, 2004; Tennant, 2001). It is not clear if Harry and Schroeder's (2000) criterion is just applicable to electronic manufacturing processes (e.g. the Motorola Company), where much of their work was carried out or whether it can be applicable to any industry. Moreover, the role of variables such as risk, complexity, new technology, time, cost and customer demands which may determine the redesign efforts are not specified. Rapid time to market, reduced use of physical prototypes, fewer defects and satisfied customers are a few of the advantages that define the appeal of the design for Six Sigma improvement methodology.

DFSS is a systematic methodology utilising tools, training and measurements to design new processes, products or services that meet customer expectations at Six Sigma quality levels (Pyzdek, 2003).

DFSS is deployed via a framework known as Define, Measure, Analyse, Design and Verify (DMADV) model as shown in Fig. 2.5.1.

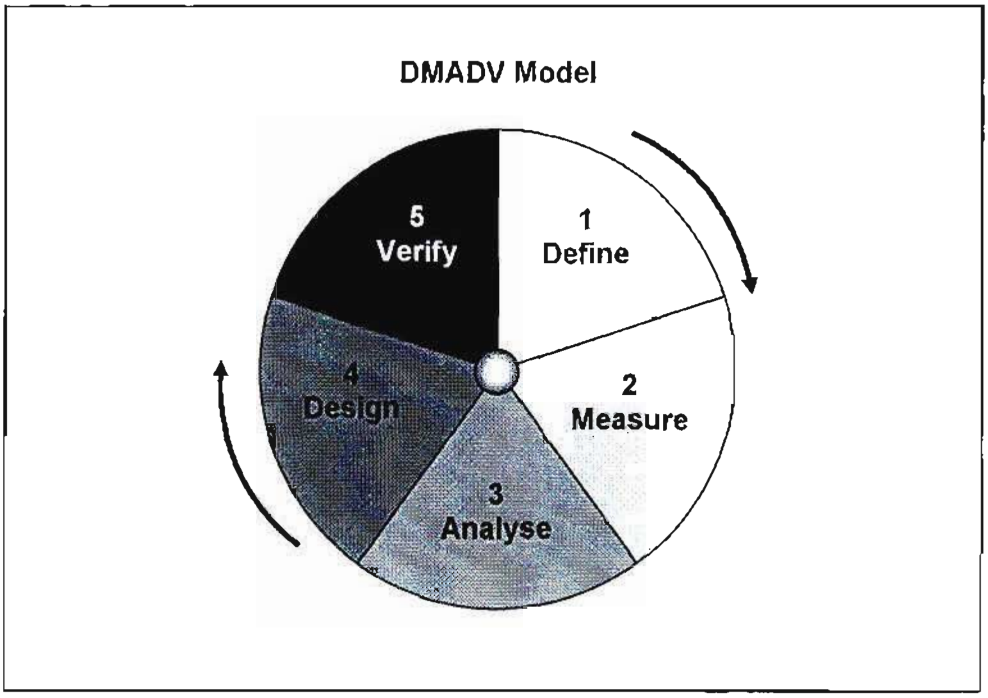

Fig: 2.5.1: DMADV Model (adapted from Picard, 2004)

The DMADV process includes the following five steps (Brue and Launsby, 2003; Picard, 2004):

- Define: Define the project, determine project goals and customer requirements.
- Measure: Quantify customer needs and specifications.
- Analyse: Explore concepts and methods of meeting customer requirements.
- Design: Develop a process to meet customer requirements.
- Verify: Ensure that the design performance has met customer requirements.

- DMADV is a five step method for designing new processes, products and services that do not currently exist.
- To improve an existing process, product or service if:
  - It is not designed for current capacity,
  - It fails to meet multiple customer requirements,
  - There are multiple fundamentally different versions in use,
  - The organisation cannot improve the process, product or service using existing technology as evidenced by repeated unsuccessful improvement attempts.
- DMADV allows the organisation to refocus on the customer requirements, ensuring greater accuracy, reduced variation and high Sigma levels from the outset.
- DFSS also integrates three major tactical elements to help attain the ubiquitous business goals of low cost, high quality and rapid cycle time from product development:
  a) A clear and flexible product development process.
  b) A balanced portfolio of development, design tools and best practices.
  c) Disciplined use of project management methods.

Six Sigma works to repair a problem at its source, however, DFSS takes it one step further back, to design flawless products and processes in the first place (Picard, 2004).

According to Brue (2002), "design for Six Sigma is a systematic methodology using tools, training, and measurements to enable the design of products, services and processes that meet customer expectations at Six Si gma quality levels. DFSS optimises the design process to achieve Six Sigma performances and integrates the characteristics of Six Sigma at the outset of the new product development with a disciplined set of tools".

DFSS may be succinctly defined as "a rigorous process for defining products, services, and / or processes to reduce delivery time, reduce development cost, increase effectiveness and better satisfy the customers" (Brue and Launsby, 2003).

According to Chowdhury (2004), design for Six Sigma attacks a company's problems at the product development stage and presents a revolutionary five step process that takes a company all the way to Six Sigma.

The design for Six Sigma process results in:

- Cost savings in development, manufacturing and after-sales service and support.
- Improved quality at introduction.
- Getting the best products to market faster and more efficiently.

Chowdhury (2004) states that "the money is in Six Sigma for design. If you change a product after it is launched it will cost you 1,000 times more than if you made those changes during the design stage". The reason to accomplish DFSS is ultimately the gain in financial benefits. It generates shareholder value based on delivering customer value in the market place. Products developed under this discipline and rigor of a DFSS enabled product development process will generate measurable value against quantitative business goals and customer requirements. DFSS helps fulfill the voice of the business by fulfilling the voice of the customer. DFSS satisfies the voice of the business by generating profits through new products. It satisfies the voice of the customer by generating value through new products. It helps organisations to meet these goals by generating a passion and discipline for product development excellence through active and dynamic leadership (Creveling *et al.*, 2003).

2.6 Typical models used in DFSS

DFSS is a popular framework for a new product, process or service development process. An ideal Six Sigma design exhibits fewer than 3.4 defects per every million opportunities. To design a system for this level of quality, the quality issues must be addressed before prototypes are designed. As a result, the envisaged solutions used to improve the product must be based on dynamic simulation using mathematical, statistical models and experimental results.

There are currently several DFSS methodologies that are being applied by various companies globally. These methods include:

- PIDOV: (Plan-Identify-Design-Optimise-Validate),

- DMADV: (Define-Measure-Analyse-Design-Verify) (Brue and Launsby, 2003; Picard, 2004),
- I^2DOV: (Invent and Innovate-Develop-Optimise-Verify) and
- CDOV: (Concept-Development-Design-Optimisation-Verification) (Creveling *et al.*, 2003).

The other prevalent method for DFSS implementation in industry is the IDOV method, consisting of the distinct phases described below:

- Identify: Select the best design concept based on the voice of the customer.
- Design: Build a thorough base of knowledge about the design.
- Optimise: Achieve a balance of quality, cost and time to market.
- Verify: Demonstrate that the design meets its requirements.

A number of well known tools are typically applied throughout the execution of the IDOV method. Development of alternative design concepts in the Identify phase is commonly conducted using the Theory of Inventive Problem Solving (TIPS), also commonly known by its original Russian acronym of TRIZ, (Altshuller, 1984) along with various brainstorming methods (Chowdhury, 2004). Requirements flow down and system performance modelling are conducted using transfer functions that may be derived from a variety of sources, including first-principles relationships from the physical sciences as well as regressions, response surfaces, simulation models or even computational finite element models. Failure modes and effects analysis (FMEA) is often applied in DFSS and may be used as early as the Identify phase to guide definition of design alternatives or as late as the Optimise phase to estimate failure rates and to identify means of reducing them. Collectively, these form a powerful, albeit loosely integrated, suite of tools for DFSS execution.

The additional DFSS techniques mentioned above are similar to the IDOV method. PIDOV consist of the four steps in the IDOV method with the addition of a Plan step. During this planning phase, all vital steps of the project are mapped out.

The I^2DOV method consists of four steps and is similar to the IDOV method. The first step is Invention and Innovation. In this phase, business goals and markets are defined, technological trends are identified and technological roadmaps are created. In the Develop stage, technology concepts are generated based on customer information. The Optimise stage consists of increasing the robustness of a design and tuning adjustment factors. Verification, the final phase, involves the integration and validation of sub-systems as well as the complete product. CDOV is similar to the IDOV method but replaces the Identify phase with a customer needs-based Concept development phase (Creveling *et al.*, 2003).

The anti-Six Sigma proponents suggest that to solve real life problems, more than one methodology and one quick fix is needed. Improvements need to be validated. They state that one must be patient enough to wait for a process to develop and verify the results based on documented proof.

Another practical challenge of implementing DFSS in large organisations is the communication required between many different groups and the total time spent on the projects. To facilitate better communication between DFSS, systems, manufacturing and management groups, a clear and consistent methodology is needed in the earliest stages of design. Consistency is also needed in representations so that prior knowledge can be reused reducing the time spent on each DFSS project.

2.7. DMADV Model – Roadmap translated from the model

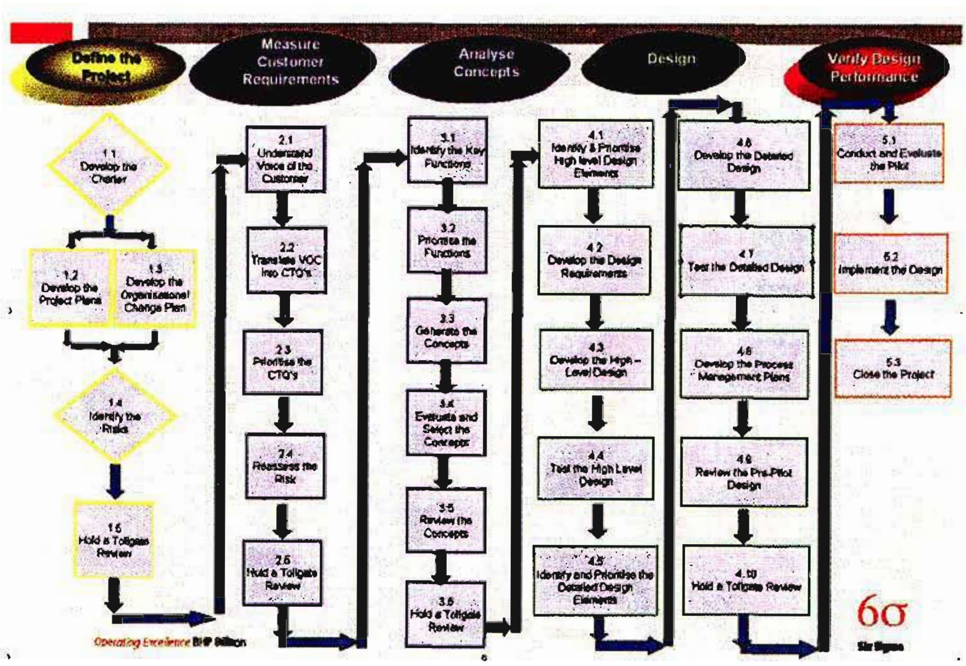

Fig. 2.7.1: DMADV Model translated to a Roadmap (adapted from Picard, 2004), Source MMC.

The DMADV roadmap shown in Fig. 2.7.1 was adapted from the DMADV model proposed by Picard (2004) which is being evaluated as the DFSS improvement methodology at Manganese Metal Company.

DFSS is an enhanced business process focused on improving profitability. If DFSS is properly applied, it generates the right product, process or service at the right time and at the right cost. Through its use of product, process and team scorecards, it's a powerful management technique programme. DFSS is an enhancement to a company's new product, process and service development and not a replacement for it. A well documented, understood and useful new product development process is fundamental to a successful DFSS programme.

This new product development process provides the roadmap to success. DFSS provides tools and teamwork to get the job done efficiently and effectively. By rigorously applying the tools of DFSS, one can be assured of predictable product quality and bottom line results.

The Table 2.7.1 below shows the five steps of the DMADV model and its associated sub steps using specific tools that generate specific outputs in the DFSS process.

Steps	Tools	Outputs
1. Define the project: • Develop a clear definition of the project. • Develop organisational change plans, risk management plans and project plans.	• Market Analysis Tools: - Market forecasting tools. - Customer value analysis. - Technology forecasting and visioning. - Competitor analysis. • Process Analysis Tools: - Control charts. - Pareto charts. • Traditional Project planning Tools: - MS Projects - Gantt / Pert charts. - Work breakdown structures. - Activity Network diagrams. • DMADV specific Tools: - Project Charter. - In scope / out of scope tool. - Organisational change plan.	• Project Charter. • Project Plan. • Organisational change plan. • Risk management plan. • Tollgate review and storyboard presentation.
Steps	**Tools**	**Outputs**
2. Measure Customer Requirements: • Collect Voice of the Customer (VOC) data. • Translate the VOC into design requirements (CTQ's) • Revise the Risk Management Plan. • If necessary develop a multistage Project Plan.	• Customer segmentation tree. • Data collection plan. • Customer research Tools: - Interviews, - Contextual inquiry, - Focus Groups, - Survey. • VOC table. • Affinity diagrams. • Kano model. • Performance bench marking. • Quality function deployment (QFD) matrix. • CTQ risk matrix. • Multistage plan. • Tollgate review form.	• Prioritised CTQ's. • Updated risk management plan and multistage project plan, if appropriate. • Tollgate review and updated storyboard.
Steps	**Tools**	**Outputs**
3. Analyse concepts: • Generate, evaluate and select the concept that best meets the CTQ's within budget and resource constraints.	• QFD matrix. • Creativity tools: - Brainstorming, - Analogies, - Assumption busting - Morphological box • Pugh matrix. • Tollgate review forms.	• Selected concept for further analysis and design. • Tollgate review and updated storyboard.
Steps	**Tools**	**Outputs**
5. Verify design performance: • Conduct the pilot, stress-test and debug prototype. • Implement the design. • Transition responsibility to the appropriate people in the organisation. • Close the team.	• Planning tools. • Data analysis tools: - Control charts. - Pareto charts. • Standardisation Tools: - Flowcharts - Checklists - Process management charts	• Working prototype with documentation. • Plans for full implementation • Control plans to help process owner's measure, monitor and maintain process capability. • Transition of ownership to operations. • Completed project documentation. • Project closure. • Final tollgate review and updated storyboard.

Table 2.7.1: DMADV methodology illustrating the steps, tools and outputs (adapted from Picard, 2004).

2.8. Roots of DFSS

DFSS has its roots in systems engineering. In turn, much of the learning's that underpins systems engineering evolved under the guidance of the Department of Defence and NASA. To control the lifecycle process, a management approach was developed that uses performance specifications as opposed to volumes of product, subsystem, assembly, part and process specifications. In the systems engineering world, management of requirements (such as those aspects of the end product that must meet customer expectations) guides and drives the entire process. Requirements at the senior or point of use level can then evolve through use of a variety of techniques generally described under the heading of requirements flow down.

When statistical or quantitative methods are used to establish requirements between system performance and underlying inputs, the design process methodology transitions from a reactive, build and test mode to a predictive, balanced and optimised progression. DFSS provides a systematic integration of tools, methods, processes and team members throughout product and process design. Initiatives vary dramatically from company to company but typically start with a charter (linked to the organisation's strategic plan), an assessment of customer needs, a functional analysis, an identification of critical to quality characteristics (CTQ's), concept selection, a detailed design of products, processes and control plans.

The beginning of the process centres on discovering customer wants and needs using tools such as Concept Engineering™ (Centre for Quality of Management) and quality function deployment (QFD). From this "fuzzy" front end, requirements take shape. Customer issues, competitive advances, technology roadmaps and disruptive influences commingle in a stew of initial uncertainty (Bertels, 2003).

2.9. The marketing basics around DFSS

Understanding the needs of the customer for a particular market segment is critical to success. It is important to get it right at this first stage. All too often, however, this does not happen. Far too often, organisations do little more than review complaints and simply ask the customers what new features they would like to have added to the product. That's valuable, of course, but it's not going far enough. Focus groups and interviews can also provide valuable information about the customer but many times respondents offer feedback couched in terms of technical solutions.

2.10. Misinterpretations about DFSS

A common misconception about DFSS is that it's a replacement for the current new product development process. If no formal process exists within any company, it could be used to guide the development process but typically DFSS provides the tools, teamwork and data to supplement the new product development process already in place in an organisation. Another misconception is that DFSS is just Six Sigma in design. The truth is that DFSS is a complex methodology of systems engineering analysis that uses statistical methods. Related beliefs are that DFSS is just Design for Manufacturability and Assembly (DFMA) and / or Design of Experiments (DOE) and Robust Design (RD) concepts in engineering.

Those beliefs are based on an overly simplified understanding of DFSS. It's actually a comprehensive process that involves DFMA issues and applies DOE and RD among many methods. Because of its use of statistical methods, people may believe that DFSS demands extensive statistical analysis and modelling of all requirements which is untrue. DFSS calls for dealing with each engineering requirement optimally. Consequently, some requirements are analysed statistically but some requirements are handled with traditional engineering methods. Another misconception is that DFSS allows too much design margin, so that costs are higher and it increases the development cycle times, so that market opportunities are missed. DFSS balances costs, cycle times, schedules and quality.

Brue (2002) states that opponents of DFSS think of it as being simply a collection of tools. This is a misunderstanding. Although DFSS uses some powerful tools, those tools alone will not ensure success, not unless those using them know how to apply them to specific engineering design opportunities. Another misconception is that DFSS involves just the core product design team and has no impact on marketing, research, and manufacturing. Because of tools recently added to DFSS, this is no longer true. The most effective product development teams are cross functional with strong project management leadership and management support. Marketing, research, design and advanced manufacturing engineering are typical representatives in a DFSS wave. The team works together to scope customer requirements, select design concepts, detail the product and process design, select suppliers and ensure that supplier capability meets or exceeds customer driven engineering needs.

According to Brue (2002), DFSS may apply to many engineering disciplines but not to all. However, since DFSS is not specific to any discipline, it applies to all. The analysis will differ according to the discipline but most of the DFSS principles will apply. Another misconception is that all management needs to do is "sign the cheque" and DFSS will happen overnight. Management must play an important role in leading the change effort. Activities such as linking the DFSS process with the company vision, establishing an executive change council to drive implementation, making successes visible, guiding implementation throughout the organisation and making DFSS integral to the company culture are all vital. Another misconception involves classroom training. Training in tools with no implementation plan does not result in cultural change. Far too many organisations develop or purchase extensive training initiatives, train employees in a classroom environment and expect implementation to just happen. Classroom training that is not integral to implementation does not work. Another approach is just-in-time training. Team members learn about a tool as they need it; initial facilitation support is provided as they learn how to apply the tool and simultaneously work on the new product.

2.11. Antecedents to DFSS

Several of the design tools and methodologies that underpin ones approach to the challenge of designing new products and services emerge from the competitive crucible of the 1980's and 1990's. American manufacturing businesses, especially in the automotive sector were keen to learn why the Japanese were so effective and discovered that the following four themes permeated the cultures of excellent Japanese companies:

Statistical thinking – The Japanese firms had built their product development strategies on a consistent diet of Total Quality Control (TQC). TQC emphasised statistical control similar to what Walter Shewhart has advocated: an obsession with ensuring that products were developed "on target with minimum variation". While the West pursued more abstract yet noble notions such as that of excellence, the Japanese were learning how to apply statistics to the problems of product and service performance. Businesses such as Ford, Xerox, Motorola and General Electric had individuals with the same statistical skills as the Japanese but the problem was that they were not really influencing leadership and business strategy.

Focussing on customer satisfaction – Japanese firms ensured that explicit, well engineered business processes had an unwavering focus on the voice of the customer (VOC).

Designing for product and process alignment – Having clearly listened to the VOC, the new product development heavyweights ensured that there were good alignment between the VOC and the product and service design concepts, using a problem solving process for overcoming misalignment issues.

Concurrent engineering – Not only did effective new product development entail significantly more rigour in the definition phase but the Japanese also succeeded in dramatically compressing new product and service development times.

These dramatic improvements in lead time were achieved by the following methods:

- High efficiency of individual design tasks.
- Simultaneous, as opposed to sequential, design activity.
- An elimination of functional interfaces in the design process.
- The creation of multi-disciplined teams.

These four teams were supported by the consistent application of three specific tools to support world class product ambitions of Japanese companies (Smith *et al.*, in Bertels, 2003).

2.12. DMAIC versus DMADV

The DMAIC model is used in the operational Six Sigma methodology for continuous process improvement. The DMAIC model focuses on incremental improvement and is complemented by the design for Six Sigma methodology which provides organisations with a structured roadmap for new product or service innovation. For existing processes that require radical redesign, DFSS could provide a means for dramatic improvement. Like DMAIC, DFSS demands unwavering attention to customer needs. This attention to the customer can lead to outstanding results.

The value of the Six Sigma methodology as a data driven strategy for eliminating defects in any process is obvious when one recognises that everything in business is accomplished through a process. Sales people utilise leads to win a sale. Production receives an order and schedules the manufacturing. The product is built, packaged and shipped. But when, for instance, the production department has a problem with its process either the operational Six Sigma or DFSS methodology is better for addressing the problem.

Both methodologies employ roadmaps. In the case of DMAIC, the methodology and the roadmap are one and the same (Define, Measure, Analyse, Improve, Control). DFSS utilises a variety of different roadmaps and the most common is the DMADV model (Define, Measure, Analyse, Design and Verify). It is at the roadmap level that the two methodologies can be compared. Both methodologies are used to drive defects to fewer than 3,4 per million opportunities, data intensive approaches to solving problems, implemented by Green Belts, Black Belts and Master Black Belts, ways to help meet a company's bottom line numbers and implemented with the support of a champion and a process owner. Both roadmaps each have five phases. Though they share three out of five phase names, the focus of each phase and the associated activities differ for each roadmap. The DMAIC model is used mostly in transactional and operational Six Sigma processes when a product or process is in existence at a company but is not meeting customer specification or is not performing adequately. This methodology and roadmap addresses the need for incremental improvement. The DMADV model is used when a product or process is not in existence at a company and one needs to be developed and also when the existing product or process exists and has been optimised, using DMAIC and still doesn't meet the level of customer specification or Six Sigma level. Table 2.12.1 summarises the key differences between DMAIC and DMADV.

DMAIC	DMADV
Define the project: • Develop a clear definition of the project. • Collect background information on the current process and your customers' need and requirements.	**Define the project:** • Develop a clear definition of the project. • Develop organisational change plans, risk management plans and project plans.
Measure the current situation: • Gather information on the current situation to provide a clearer focus for your improvement effort.	**Measure the customer requirements:** • Collect the Voice of the Customer (VOC) data. • Translate the VOC into design requirements (CTQ's). • Develop a phased approach if necessary.
Analyse to identify causes: • Identify the root causes of defects. • Confirm them with data.	**Analyse concepts:** • Generate, evaluate and select the concept that best meets the CTQ's within budget and resource restraints.
Improve: • Develop, test and implement solutions that address the root causes. • Use data to evaluate results for the solutions and the plans used to carry them out.	**Design:** • Develop the high-level and detailed design. • Test the design components. • Prepare for pilot and full scale deployment.
Control: • Maintain the gains that you have achieved by standardising your work methods or processes. • Anticipate future improvements and make plans to preserve the lessons learned from this improvement effort.	**Verify design performance:** • Conduct the pilot and stress-test and debug the prototype. • Implement the design. • Transition responsibility to the appropriate people in the organisation. • Close the project.

Table 2.12.1: DMAIC versus DMADV (Adapted from Picard, 2004)

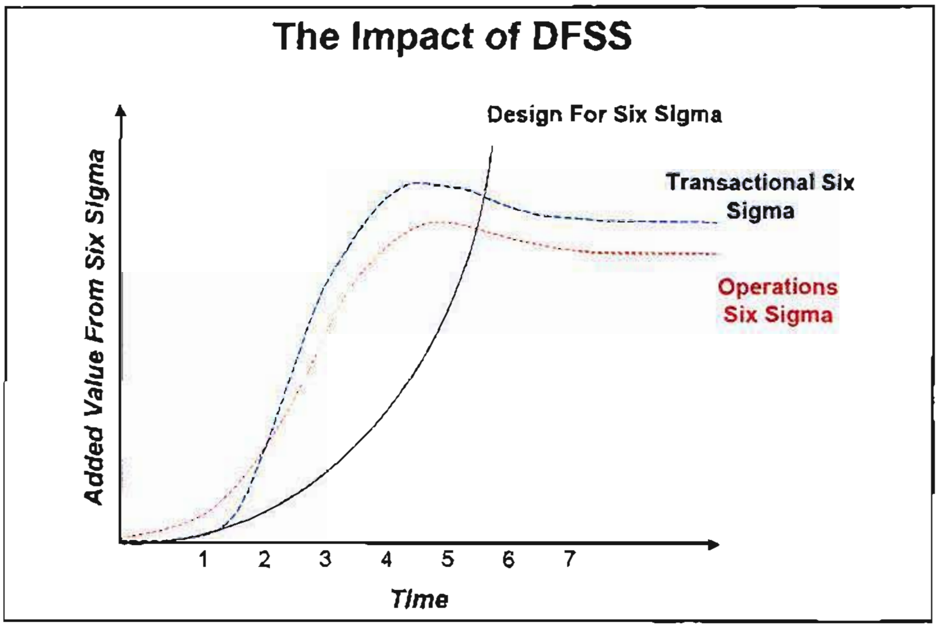

Figure 2.12.1: Comparison between DFSS, Transactional Six Sigma and Operations Six Sigma (Internet 6)

Fig. 2.12.1 illustrates when the DMADV model is used, DFSS would generate added value and yield greater returns over time when the new product is designed for Six Sigma reliability at the start of the process compared to transactional and operations Six Sigma which uses the DMAIC model.

DFSS is a powerful approach to designing products, processes and services in a cost effective and simple manner to meet the needs and expectations of the customer while driving down quality costs. It involves the utilisation of powerful and useful statistical tools to predict and improve quality before building prototypes. It is a methodology to make the introduction of new products, processes and services more efficient, reliable and capable of meeting high customer expectations and requirements. DFSS has the potential to simplify new design and redesign configurations, it eliminates non-value added steps or processes in the design of a new product, process or service and hence, reduce material, labour and overhead costs. The DFSS approach seeks inventive ways of satisfying and exceeding customer requirements and expectations.

DFSS is the most effective means of realising the full benefits of Six Sigma capability. It ensures that the concepts and principles of Six Sigma are applied at the production design and development stages for enhanced customer satisfaction, improved long term profitability, increased product reliability, suitability, marketability and improved profit margin, however, successfully applied, DFSS does prove to be a means of harnessing the best design practices to achieve competitive advantage and business excellence.

DMAIC and DMADV projects are usually managed by both Black Belts and Green Belts. Black Belts are typically full time resources responsible for implementing and managing the large Six Sigma projects. Green Belts are typically part time resources spending forty percent of their time working on smaller size Six Sigma projects. World class Six Sigma companies usually have approximately one percent of their workforce working as full time trained Black Belts compared to five percent for the Green Belts working on a part time basis on improvement projects.

The front line leaders of Six Sigma are called Black Belts. These individuals are full time project leaders with all the same responsibilities as Green Belts. However, Black Belts receive significantly more training than Green Belts. Black Belts usually receive four weeks compared to Green Belts of one week training and are expected to generate more results from larger scope projects (Hoerl *et al.*, 2001). Black Belt candidates are described as disciplined problem solvers who possess a fair amount of technical ability, are comfortable with basic statistics, and are not afraid to question conventional wisdom (Hoerl *et al.*, 2001; Adams *et al.*, 2003). A Black Belt has also been described as an open mined change agent and project manager who must be able to communicate effectively at all levels (Brue, 2002). Six Sigma subject matter experts have insisted that black belts be able to use a broad set of soft skills, such as meeting management and presentation methods (Breyfogle *et al.*, 2001; Eckes, 2001b; Hoerl *et al.*, 2001; Pyzdek, 2003). As a chosen leader, the Black Belt will guide a team through DMAIC and DMADV.

Black Belts are "future business leaders" (Eckes, 2001b, p. 43) and "the backbone of Six Sigma culture" (Brue and Launsby, 2002, p. 86). Adams *et al.*, (2003) insisted that Black Belts are in strong demand and should be selected based on management potential. Their voluntary assignment is usually temporary lasting anywhere from two to three years. These trained individuals are expected to focus their efforts fulltime in the Black Belt role over a two to three year period and are not to be distracted with tasks from the role they temporarily left. Under these conditions, a Black Belt can complete approximately four to six projects in a twelve month period. There is generally an estimated annual savings of one million dollars in total for all projects completed in this timeframe (Adams *et al.*, 2003; Harry, 1998; Hoerl, 1998).

During the literature review, DFSS topic searches using the annual company reports, intranet and internet search engines resulted in no examples being found in the literature search in which the DMADV model was used for new products, processes or services design at MMC and any of the BHPB CSG's. However, DFSS examples were found in other organisations, e.g. General Electric, 3M, Motorola, Sony, Ford, Caterpillar and Allied Signal.

This research is important because it is an original study which demonstrates the impact of the DFSS continuous improvement methodology on a new product design and its financial performance within MMC which is discussed in chapter four as the case study. The research provides a unique comparison of the EBIT financial results between the lean, Six Sigma, DFSS and replication projects at MMC as shown in chapter five. It also contributes to the literature on the effects of implementing DFSS in order to attain the FY09 OE strategic objectives within MMC and BHPB.

2.13. Conclusion

This chapter was concerned with the literature review of the design for Six Sigma methodology identifying the relevant concepts and techniques. It was followed by a discussion on the definition, tools, types and models of DFSS. It also positioned the research within MMC and BHPB. The next chapter discusses the methods used in obtaining the data for the research.

Chapter 3

METHODOLOGY

3.1. Introduction

This chapter focuses on the methods used in obtaining the data for the research. Action research methodology was used. It also describes and justifies the research methods for investigating the area of the study.

3.2. Research methodology

The research methodology was developed primarily on action research. Hult and Lennung (1980) meticulously define action research as "a research strategy which simultaneously assist in practical problem solving and expand scientific knowledge, as well as actors, being performed in immediate situation using data feedback in a cyclical process aiming at an increasing understanding of a given social situation, primary applicable for the understanding of change processes in social systems and undertaking within mutually acceptable risk". The assumptions in which action research is based are placed within the phenomenological paradigm (Hussey and Hussey, 1997).

The study of new or changed techniques and methodologies implicitly involves the introduction of such changes and it is necessarily interventionist. From the collaborative companies' viewpoint, the study of a technique is impossible without intervening in some way to inject the new technique into the company's environment (Coghlan and Brannick, 2001).

Action research is one of the few valid research approaches that can be legitimately employed to study the effects of specific alterations in systems development methodologies in organisations (Baskerville and Pries-Hege, 1999). Action research is an "organic" process involving systematic and sometimes interactive stages. It is performed in a cyclical process which aims to increase understanding of a given situation (Baskerville and Wood-Harper, 1996).

This cyclical process is not a random method; it is systematic, involving a self reflective spiral or cycle of planning, acting and fact finding through self reflecting (McNiff, 1998). This research starts by establishing the theoretical foundation of the research and selecting a research design. After that, the core action research cycle is carried out which follow the planning, action and reflecting phases. Rigorous reflection about the actions, methodologies, the underlying assumptions and perspectives make this reflection to an innovative application of knowledge and gives the appropriate research reliability (Coughlan and Coghlan, 2002).

3.3. Significance of the research

This research is important because it is an original study which demonstrates the impact of the DFSS continuous improvement methodology on a new product design and its financial performance within MMC which is discussed in chapter four as the case study. The research provides a unique comparison of the EBIT financial results between the lean, Six Sigma, DFSS and replication projects at MMC as shown in chapter five. It also contributes to the literature on the effects of implementing DFSS in order to attain the FY09 OE strategic objectives within MMC and BHPB. This research also offers further support for a fundamental premise in the field of management of change. Cunningham (1995) in Saunders *et al.*, (2003) states that action research is one of the first common themes in management research that focuses on and emphasises management of change.

Eden and Huxham (1996:75) in Saunders *et al.*, (2003) argue that the findings of action research result from the "involvement with members of an organisation over a matter which is of genuine concern with them". Therefore the research is part of the organisation within which the research and change process are taking place according to Zuber-Skerritt (1996) in Saunders *et al.*, (2003).

Action research differs from other forms of applied research because of its explicit focus on action, in particular promoting change within the organisation according to Marsick and Watkins (1997) in Saunders *et al.*, (2003). As Coghlan and Brannick (2001) in Saunders *et al.*, (2003) note: "the purpose of action research and discourse is just not to describe, understand and explain the world but also to change it". Saunders *et al.*, (2003) states that in addition the person undertaking the research is involved in this action for change and subsequently application of knowledge gained elsewhere. The strengths of an action research strategy are a focus upon the change; the recognition that time needs to be devoted to reconnaissance, monitoring, evaluation and the involvement of employees throughout the process. Schein (1995) in Saunders *et al.*, (2003) emphasises the importance of employee involvement throughout the process, as employees are more likely to implement change they have helped to create. Action research therefore combines both information gathering and facilitation of change.

3.4. Objectives of the research

The objective of this dissertation was to identify why the DFSS methodology becomes a priority in the BHPB business improvement plan, to test the applicability and to determine the use of the DFSS methodology for a new product design. To evaluate DFSS for a new AMT product design project and the impact it has on EBIT, net present value and internal rate of return. To evaluate the impact of DFSS on the BHPB's operating excellence strategic objectives.

The focus of the study will be:

- To evaluate the DFSS process and whether it is suitable to achieve the desired end result that is expected for new product design at MMC. An analysis of the impact of using DFSS in a new product design using some of the tools would be carried out and an evaluation of this methodology will be undertaken against the DMADV model.

- To establish the impact of the DFSS process on BHPB's FY 2009 OE objectives and the delay of implementing a DFSS project and its effect on NPV and IRR at MMC. Data will be collated for the years 2001 to 2005 for analysis. Comparison of the data will be able to give an indication of the extent to which the company has achieved its OE strategic objectives, the pace of its performance and whether it would successfully achieve its FY 2009 targets and how can DFSS contribute to the bottom line of the FY 2009 targets.

In so doing it is hoped to discover any flaws in the research process so that appropriate recommendations and an action plan could be proposed to management.

3.5. Research design

The research technique involved the collection of quantitative data. A view shared by Ghauri and Gronhaug (2002) where they state that a case study may very well involve quantitative methods or even be entirely quantitative. When the key aspects of DFSS were identified, the research was designed to verify the effects of DFSS on a new products financial performance and to assess the significance between the different business improvement methodologies at MMC. The research was also designed to assess the impact of the Six Sigma financial performance on BHPB's FY09 OE strategic objectives whilst comparing the performance of the other CSG's using GE as the benchmarked standard.

The first target population chosen for the research investigation was MMC to discuss the DMADV model on the new AMT product design, to assess the new AMT products financial performance with respect to EBIT and to analyse the differences in EBIT means in order to test the financial significance between the alternate business improvement methodologies at MMC.

The second target population chosen for the research investigation was the eight CSG's within BHPB which included, Aluminium, Base Metals, Carbon Steel Materials, Diamonds and Specialty Products, Energy Coal, Stainless Steel Materials, Petroleum and BHPB Corporate which had adopted the Six Sigma methodology from 2001. The research design aspects were compared between each CSG using GE as the benchmark.

The research design was conducted within the Six Sigma OE programme relating to the following aspects:

- Use of the DFSS methodology for new products,
- Six Sigma total improvement benefits reported,
- Each CSG's Six Sigma metrics versus world class benchmark,
- Number of Black Belts and Green Belts trained,
- Number of Black Belt and Green Belt projects completed,
- Number of active Belts as resources working full time.

Ghauri and Gronhaug (2002) states that it is the research problem and the research objectives that influences the number and choice of cases to be studied. Campbell (1975) in Ghauri and Gronhaug (2002) states that this will provide variability among important factors and argues for the richness of detail within a single case by looking for multiple implications of ideas under study. There is no upper or lower limit with regard to the number of cases to be included in a study (Ghauri and Gronhaug, 2002). Ghauri and Gronhaug (2002) states that the case study method is used when we want to study a single organisation and we want to identify factors involved in some aspects of an organisation such as the finance department. However, it is equally possible to study a number of organisations with regard to a set of variables we have already identified or assumed. Such case studies are called comparative case studies. In this type of study the same types of questions are studied in a number of organisations and are compared with each other to draw conclusions (Ghauri and Gronhaug, 2002).

3.6. Data collection

The purpose of data collection in the comparative case study method is to compare (replicate) the phenomenon (e.g. strategy formation) studied in different cases in a systematic way, to explore different dimensions of our research issues or to examine different levels of research variables (Ghauri and Gronhaug, 2002). According to Bonoma (1985) in Ghauri and Gronhaug (2002), case research is based on a process model and involves data collection through multiple sources such as verbal reports, personal interviews and observation as primary data sources. In addition, case methods also involve secondary data collection through sources such as financial reports, archives, budgets and operating statements, including market and competition reports. Also data was collated in the areas of operating excellence, projects, quality and production reports. This was available from the company's monthly, quarterly and annual reports. Selltiz *et al.*, (1976) in Ghauri and Gronhaug (2002) states that this approach relies on the integrative powers of research: the ability to study an organisation with many dimensions and then to draw an integrative interpretation.

Other secondary data sources that were used for the research included intranet sites of MMC and BHPB CSG's, weekly production reports within MMC, internet sites and web pages of different companies and organisations that are currently involved in or implementing DFSS, academic as well as organisational journals and newsletters relevant to DFSS, textbooks and other published material directly and indirectly related to DFSS and lastly theses and reports written by other students relevant to Six Sigma. Ghauri and Gronhaug (2002) states that secondary data can help researchers in the answering of research questions or solving some or all of the research problems, it also provides benchmarking measures and other findings that can be compared later on with the results of the study at hand. Ghauri and Gronhaug (2002) also states that doing research in a company / organisation will be facilitated by the fact that other departments / sections of the organisation might have the information needed to answer the questions at hand.

3.7. Data analysis

The purpose of the data analysis was to explore the relationship between the data gathered using statistics to answer the critical questions of the research.

Multiple bar charts were used to compare the trends of two or more quantifiable variables within the BHPB CSG's for the same time period on the existing Six Sigma programme. Using the statistical analysis software, Minitab version 14, a one-way analysis of variance (ANOVA), was completed to test for any significant differences in the sample means for EBIT between the various business improvement methodologies, i.e. (Six Sigma, DFSS, lean Sigma and replication Six Sigma projects from other CSG assets), currently being assessed at MMC at a pre-feasibility stage. The ANOVA statistical method of analysis was more suitable than any other methods of analysis because ANOVA is suitable for analysing the variations within and between groups of the alternate business improvement methodologies EBIT data by comparing the means.

3.8. Conclusion

This chapter discussed the methods employed for the research and how the data was obtained for analysis. The following chapter discusses the case for DFSS with respect to the new product design employing the DMADV model encompassing some of the DFSS tools and techniques.

Chapter 4

THE CASE FOR DFSS

4.1. Introduction

This chapter discusses the case study pertaining to the new product design with respect to the design for Six Sigma methodology in action. The development of the new product design from concept to commercialisation was initiated using the DFSS DMADV model discussed in chapter two.

Some of the compelling reasons for redesigning the new product were due to poor product quality which resulted in recurring customer complaints (MMC Management Information System, 2005) and the loss of key customers to competitors which resulted in a downward trend of market share. The implementation of operational Six Sigma improvements to the existing process and product did not make a major difference to the product quality. The process sigma parameters were improved from 1.6 to 3.6 Sigma quality level. The goal was to redesign the product and process to Six Sigma quality levels.

4.2. Background to the case study

MMC currently produces and sells a range of manganese products that are used in the aluminium industry as alloying hardeners. These products include manganese powders, flakes and aluminium manganese briquettes (AMB) (Internet 6). The AMB product was a cash cow for the past decade due to MMC being the only supplier of the product to international markets. Over the past few years, market demand increased and new competitors emerged to fulfil the new market requirements. MMC over utilised the existing production capacity to meet the new market demand and to compete in order to gain total market share. This resulted in numerous operational Six Sigma continuous improvements being implemented to the existing AMB manufacturing process to improve the overall process efficiency to achieve a local maximum plant performance to increase product yield, however, this performance was not sufficient to meet MMC's competitive requirements resulting in the AMB product quality deterioration. Numerous product quality customer complaints were registered from majority of the MMC external customers.

The poor operations management of the existing equipment, higher production yields than design capacity and compromised scheduled maintenance were some of the other factors that contributed to the deterioration of the product quality.

During the end of 2004, a technical audit was commissioned to investigate the market share decline due to customer complaints, assess the existing process, products and to advise a suitable correction plan.

4.3. Define the project and the customer requirements

The aims of the define step were to develop a clear definition of the project, the customer requirements, the project charter, the project plan, the risk and organisational change management plan. It also evaluated the market feasibility and the risk of alternate concepts for the new product design and development.

In 2005, MMC experienced the negative impact of financial losses related to the poor quality of the AMB product due to key operational and equipment failures. The motivation for the business case was clear, a superior quality redesigned product results in happier customers which lead to higher margins and greater market share. The operational and product quality risk was defined as the risk of loss resulting from inadequate or failed internal processes, people and systems, or from external events. The results of the internal audit found that this issue was pervasive in the AMB product process which showed that 97% of the quality problems were due to operational failures being equipment, people and systems. When the project was chartered, the original risk assessment process was mapped at a high level and it was found that the internal process design requirements, systems, operating and maintenance procedures were compromised which impacted on the AMB products poor quality.

The AMB products quality data were analysed using pareto and control charts to make a few preliminary conclusions.

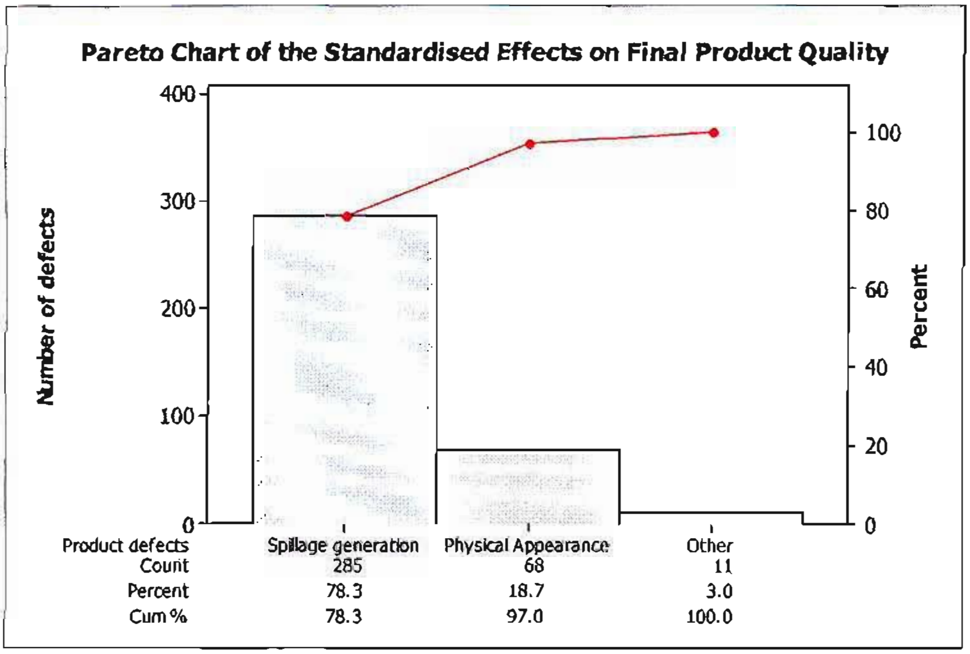

Figure 4.3.1: Pareto chart of the standardised effects on final product quality (Source: MMC management information system).

The plot of the pareto chart in Figure 4.3.1 showed the defects that compromised the AMB final product quality the most were the spillage generation. Spillage generation in final packaged bags was one of the key problems experienced with the production of AMB product. The physical appearance of the AMB product was another problem as the edges were always friable which contributed to the high spillage generation in the final packaged bags. Numerous customer complaints were received relating to the fines generation in the packaged bags. This helped to focus the improvement efforts on the areas where the largest gains could be made. A routine survey was completed to determine the amount of spillage generated from the final product in its respective packaging.

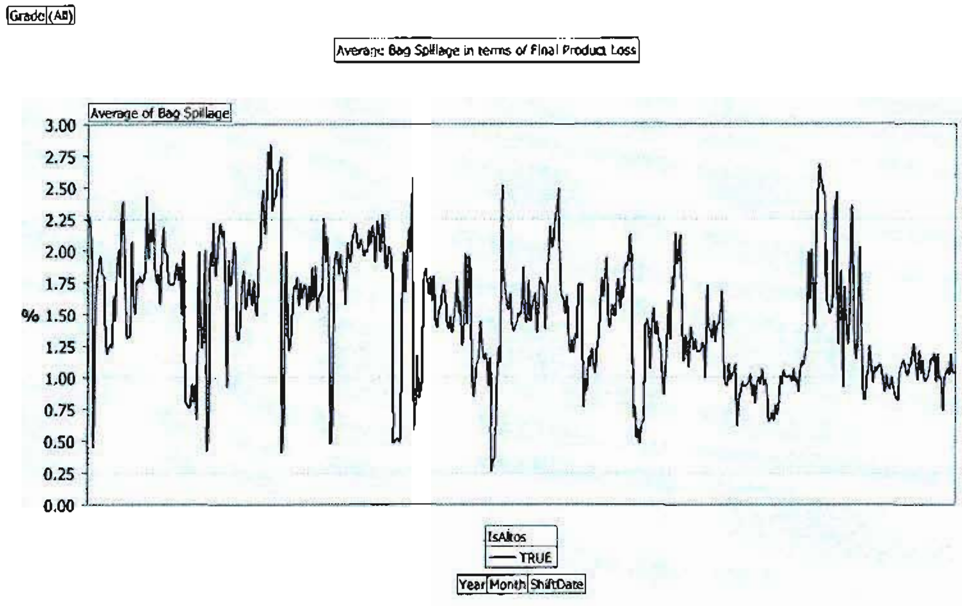

Figure 4.3.2: Run chart of bag spillage (Source: MMC management information system)

A run chart of the average bag spillages as shown in Figure 4.3.2. were plotted and the root cause analysis revealed that the final product friability was a key contributor to the AMB poor product quality.

During the define step the new product concept was established, namely an aluminium manganese tablet (AMT). The decisions were based on the projects financial justification, market research, customer analysis, competitor analysis and emerging product technology based on the existing AMB and other products in the similar category. A key market segment in Europe, USA and Japan was, however, supplied by alloy tablet products. By extending its range of product offerings MMC will be able to compete and position the new product in this market.

A business case was developed for capitalising the new opportunity in MMC's technology strategic portfolio product line plan. A project charter was developed to gain what was expected from the project. It was stated that the project objective is "…to establish MMC as a world class supplier of high quality aluminium manganese tablets for the aluminium alloying industry..." (Source: MMC: Project Charter - 2005).

The project charter highlighted the need to address the loss of customers due to the poor quality product supplied, the decrease in market share due to new entrants and competitors in the market. The opportunity statement addressed the potential expansion of existing marketing segments, acquiring new market segments, positioning and launching the product in niche markets and the financial benefit for launching the new redesigned product. The DFSS scorecard highlighted that the AMT product could net R2000 per ton profit as a new product compared to R600 per ton for the existing AMB product, increased production capacity of 10 times more using one unit operation for the new product compared to the existing Six unit operations of the AMB product process. It was also stated that the new AMT product cost of production would be 50% cheaper than the existing AMB product and some of the cost savings will be passed on to customers in order to gain market share.

The AMT product quality benefits that were highlighted included:

The AMT quality product would conform to a process capability (Cp_k) of 2.

The AMT product would be designed for Six Sigma reliability, i.e. 3.4 defects per million opportunities.

The new AMT products chemical and other physical properties would be maintained at current performance standards.

The AMT product would be designed to have rapid dissolution rate with a high manganese elemental recovery in the aluminium alloying process.

The proposed new tablet press unit operation design would address the problem of friability experienced with AMB product.

Superior quality with respect to a dimensionally consistent new AMT product with added value was expected from the new product.

The project schedule highlighted that the overall project needed to be completed within one year from concept design. The critical milestones of the project were the new product unit operation tablet press design, market penetration and acceptance by customers. An organisational change plan was developed to show who the change impacted and when the applicable departmental support was needed in the project cycle. Change is difficult for many people because "the way things are" is comfortable and often is part of their identity. In order to help people become supporters of change the project communication was vivid on why change was needed, e.g. poor quality production, loss of customers, customer dissatisfaction and competitive pressures. All the employees who were affected by the change were allowed to express their fears and concerns during the focus group and project meetings. Some of the change strategies centred on communication, others wanted to be invited to the project meetings and some employees were involved in most of the teams activities where they were also included in key design decisions and project reviews.

A risk management plan was used to mitigate the risks associated with the new product and process design project (BHP Billiton HSEC Policy and Guidelines, 2004). Due to BHPB's zero harm policy a comprehensive hazard identification risk management assessment and hazard operability study was conducted on the new AMT product and process design. Employees of all levels that were affected by the change were invited to the risk review meeting. Some of the common potential risks identified included inadequate new customer and business information, inadequate measures for the new product and process design unit operations, a rapidly changing global environment, a tendency for the project scope to extend beyond the initial project boundaries, changes in resource availability, the envisaged capital expenditure required due to the project not being budgeted for and ad hoc capital expenditure would be requested, the complexity and unproven new technology being investigated, the design and delivery of the new process unit operation.

A tollgate review was held at the end of the define stage of the project to update the understanding of how the project progressed and how the new information affected the business case, the business strategy to which the design was linked, the project schedule, the resourcing needs and the capital investment requirements. The tollgate review also provided an opportunity to establish the common understanding of the projects efforts to date, ensured alignment of the project and reinforced the priorities, provided guidance and direction, demonstrated support for the project, it provided ongoing coaching and instruction, it also helped gather data across the projects strengths and weaknesses thus enabling better support and planning and most of all it ensured progress of the new AMT product design project.

4.4. Measure the customer requirements

The objective of measuring the customer requirements were to translate the design concept into the new product concepts that were aligned with the needs of the customers in the products targeted market segments. The measure phase of the model identified the expectations of a group of targeted customers through an in depth customer value analysis and it also determined which product functions were aligned to these expectations that made the product as competitive as possible via alternate designs.

4.4.1. Voice of the customer

According to Picard (2004), the term voice of the customer describes customers' needs and their perceptions of the new product, process or service and it includes all the aspects of the relationship with the customer with regard to quality, cost and delivery. Measuring the customer requirements helps translate the voice of the customer (VOC) into critical to quality (CTQ's) requirements for the new product design.

The VOC data that was gathered for the project helped to align the design and improvement efforts with MMC's business strategy, helped to decide which part of the new AMT product and process to enhance, identified the critical features and performance requirements for the new product and it helped identify the key drivers of customer satisfaction. The potential customers that were identified as part of the survey to add value to the new product design included existing customers who bought the AMB products, customers who stopped buying the AMB products due to quality problems, customers who purchased from direct competitors and existing customers who choose different products to meet their needs. The survey was also sent out to strategic partners, leading thinkers, subject matter experts, technology leaders in the industry, internal customers and stakeholders.

A customer segmentation tree was used to define the various customer segments. The MMC business customers were segmented according company demographics in terms of industry, size and location, operating variables such as technologies used, products used, brands used, technical strengths and weaknesses, financial strengths and weaknesses. The purchasing approach focused on the powerful influencers, policies and the purchasing organisation. Situational factors such as urgency of order fulfilment, product application, size of order, personal characteristics such as buyer and seller similarity and attitude towards risk.

4.4.2. Collection of customer needs data

Reactive and proactive systems were the two basic systems that were used to collect the customer needs data and to capture the customer information. The reactive sources helped capture all of the ways in which customers communicated their needs, mostly from technical visits and support calls, product return information and all the customer complaints that were registered over a period of four years. The data was categorised and analysed from the quality incident reporting information system. After reviewing the data periodically, the trends and patterns that were identified showed a recurring complaint from the customer on the quality aspect of the product, the physical aspect of the product was a major concern, a lot of fines generation was in the product package due to the friable nature of the final product, the attributable cause being from the production process. The reason the data collection was started from the reactive data was of the easiness to obtain the data and the basic understanding of the customer concerns thus allowing to better focus on the proactive work. The proactive sources which included interviews, market research and monitoring, sales visits, benchmarking and quality scorecards which helped capture the data on the un-stated needs which validated the assumptions about the customer needs. Information were followed up from the proactive systems to better expand the understanding of the customer needs and to quantify the importance that the customers placed on the various characteristics of the product.

4.4.3. Translation of the VOC into requirements (CTQ's)

A VOC table was developed to structure, sort and translate the customer needs into solutions, targets, measurements and other types of comments. The customer requirements were translated into critical to quality measures. The most important customer quality requirements were the mass, the physical dimensions of the AMT product and the dissolution recovery rate of the elemental manganese metal in the molten aluminium recipe. The critical to quality target specification limits that the customers were willing to tolerate were a AMT product of 50□1mm diameter, thickness of 15□0.5mm, mass of 135 □2 gram, a dissolution recovery rate of greater than 95% within 2 minutes of addition into the molten alloy recipe. Performance benchmarking was used to compare the products performance capabilities against industry benchmarks.

A quality function deployment (QFD) matrix was used to summarise the research data. A detailed QFD analysis was completed to recognise the opportunities to leverage the design efforts thus identifying the optimum trade offs for the new AMT product design. After prioritising the CTQ's, a CTQ risk matrix was completed to highlight all the risks associated with not meeting the target performance requirements. One of the key issues that was highlighted during the CTQ risk review was that a phased approach was needed to be adopted to meet the AMT product performance targets, this was executed by developing a new base AMT product line along a new process design platform on which further enhancements to the new AMT products could be used to be built upon.

Once the QFD risk review was completed a multistage plan was developed to keep the scope of the project contained so that it was manageable. It also specified the phases that would be used to implement the new AMT product design. This ensured that the first generation of the new AMT product design got to the market within the specified time window and it also provided a market presence for MMC while implementing the later stages of the new process design.

During the last stage of the measure step of the project a tollgate review was completed to finalise the customer segmentation strategy, the top five customer needs and the CTQ targets were listed, the benchmarked information was summarised, the approved multi-stage plan was signed off and it helped plan for what needed to be done in the analyse step of the project.

4.5. Analyse the concepts and high level design options

The objective of the analyse step was to translate the new AMT product concept into a high level product design and to characterise the technological and business risks associated with the scaled up new product development and marketing plan. Association methods such as brainstorming sessions were completed to generate the concepts for the new AMT product and process design. An analytic systems method tool called the morphological box was used which provided systematic guidance in constructing the innovative concepts for the new AMT product and process design. A top-down approach was used for the new AMT process equipment designs. Once the new concept designs were finalised, a step by step procedure was developed through the high level design process and finally to the detailed designs which ensured that there were a degree of confidence that the selected designs performed as required by the CTQ's.

A Pugh matrix was completed to produce more innovative and robust equipment designs by comparing the design concepts and integrating the best features from various concepts to super optimum concepts. A design review was completed which ensured the effectiveness of the features provided by the proposed design would meet the customers aesthetic and performance needs. Finally a tollgate review was completed at the end of the analyse step, the key learning's were discussed from the define, measure, analyse steps and the key design functions and responsibilities for the design step of the project were listed.

4.6. Design the process

The objective of the design step was to translate the high level product design into a detailed engineering level design, to test the design components and prepare for the pilot and the scale up deployment of the new AMT product and unit operation design. This two phased high level and detailed design approach allowed, firstly to make decisions about the major unit operation design components and how it fits together before expending effort and money on detailed decisions, resulting in a more stable and robust design, secondly to evaluate the performance and feasibility of the high level design before spending more resources on the detailed design (to make the design process more cost effective and efficient) and lastly to better understand the risks associated with the design. The design step of the project was faced with the challenges of the process design that simultaneously balanced the benefit, cost and risk elements that were compatible with the strategic decisions. Designing the new product and process together firstly allowed the process capabilities to be addressed by the overall design, secondly the rework steps to be minimised by the design and lastly the data collection for ongoing monitoring to be designed into the process.

Once the high and detailed level design was completed a pilot scale test was completed at Walch Engineering. After two months of pilot testing, the final equipment functional specification was completed for the new AMT product process equipment. The y = f (x) formula was used to describe the relationships between the CTQ's and the process variables that impacted on the CTQ's. This formula was a simple way to illustrate the causal relationship between the CTQ's and the design elements and showed which variables or inputs would be needed to control to ensure that the design would meet the performance requirements.

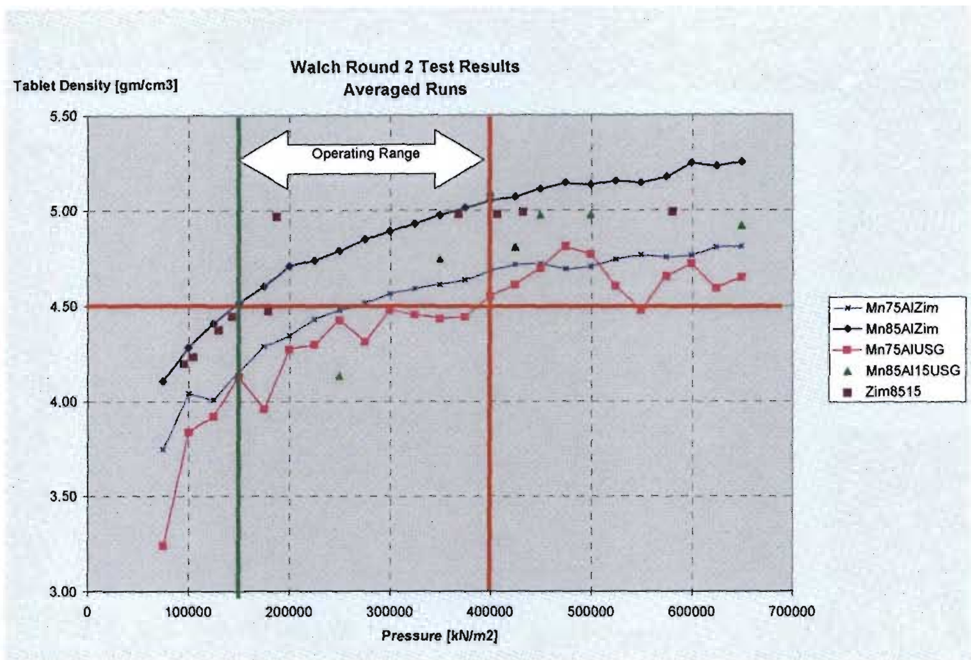

Figure 4.6.1: New AMT products density attribute (Source MMC).

Figure 4.6.1 shows the results from pilot scale plant tests conducted at the new process equipment supplier. It shows the relationship of the response or output, y = tablet density as a function of the variable x = hydraulic pressure which directly affect the output (y). The operating range for the new product was established between 150000 to 400000 kN/m^2 pressure. The pilot tests concluded that the higher the pressure the higher the product density and thus the new AMT product dissolution rate would be an optimum between the operating range. The results from the pilot testing proved positive and a prototype of the proposed new equipment was designed. The prototype was designed to test more than five elements of the proposed new product design in greater detail and to conduct customer acceptance trials with the new

AMT product. Testing and customer acceptance trials took four months to complete.

4.7. Verify design performance

The objectives of the verify step were to translate the detailed engineering level design into an optimised design process with the new product that would be offered to the customers. This step validated the new AMT product and the process design plans. It also provided the formal documentation for the full scale production in preparation for handing over the new equipment design to the process owner. The new process design was implemented in the plant, a process capability analysis was used to assess the new measurement system. During the pre-commissioning activity the new process Sigma determined was 5.5 compared to the existing AMB process of approximately 3.6 before the redesign effort. This new Sigma level established a new baseline on the project. After one month of fine tuning the AMT production process, the process Sigma level of 6.0 was attained as seen in the Figure 4.7.1.

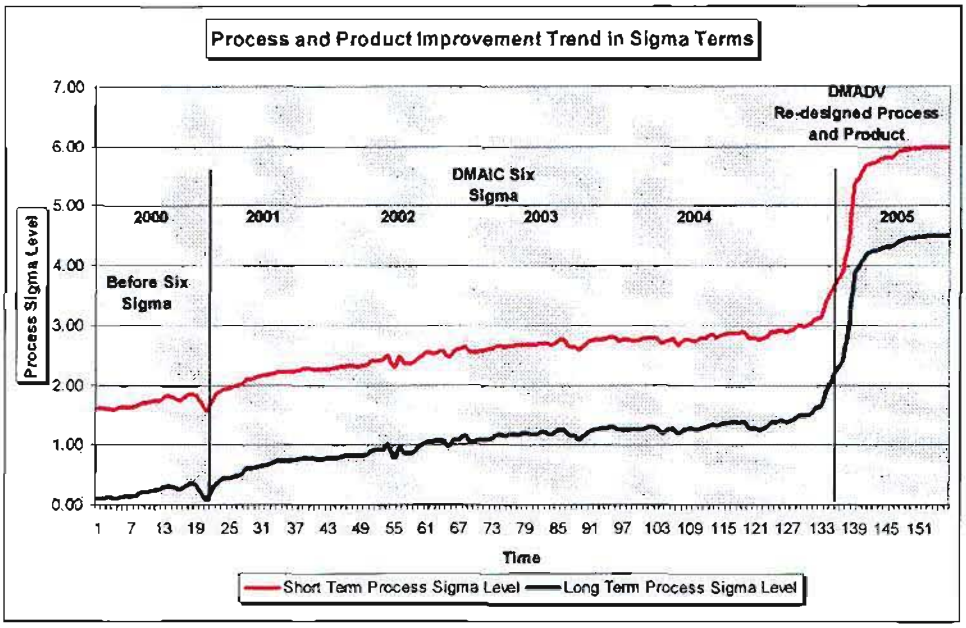

Figure 4.7.1: Process improvement trend showing the short and long term process Sigma level of the new AMT product (Source MMC).

4.8. Conclusion

This chapter discussed the case study with respect to the new AMT product and process design employing the DMADV model encompassing some of the DFSS tools and techniques. The next chapter discusses the results of the financial evaluation and the strategic plan of the new AMT product using the DFSS financial metrics with respect to the case study.

Chapter 5

RESULTS AND DISCUSSIONS

5.1. Introduction

The following chapter discusses the results for the DFSS project with specific reference to the traditional financial project measures of net present value and internal rate of return. The results of the analysis of the strategic plan as well as the findings of the research are also discussed.

5.2. Financial analysis

The capital investment cost for the pilot plant new AMT product equipment was R650 000. During the first year the total net profit for the new AMT product forecasted was estimated at R0.48 million based on the initial customer acceptance trials. The total capital investment cost for the transitional commercial scaled up to steady state process plant for producing the new AMT product was estimated at R6.02 million.

The typical market information for the new AMT product which would be commercialised with a projected sales price of R15.00 per kilogram (kg), since the AMT is a new product without current commercial sales, it was estimated with a 95 percent confidence that the actual sales price could be anywhere from R14.00 to R16.00 per kilogram.

Marketing trials also indicated that the customer would not accept the new AMT product with a mass specification less than 148.5 grams or greater than 151.5 grams (Target = 150 grams with a standard deviation = 1.5 grams). The commercial sales volumes were projected at 7.5 million kilograms per year each year for the next 10 years. The total operating expenses for manufacturing of the new AMT product were projected to be R13 per kilogram produced with an operating yield of 99% first grade product per kilogram of production. It was projected that 7.5 million kilograms of the product will be sold during 2007 and each succeeding year for the next 10 years. After 10 years it is believed that the product will no longer be viable in the market place. The total investment including technical development and capital equipment was estimated at R6.02 million prior to any sales revenue being generated. MMC's cost of capital is currently 12 percent and its tax rate is 29 percent. Sales of the new AMT product are scheduled to begin 1 June 2007. It was estimated that the product will be ready for commercial sales from the manufacturing facility within 6 months, i.e. by 1 December 2007.

The DFSS methodology and tools can reduce the time to market for the new AMT product by 3 months, reducing the commercialisation time from 9 months to the projected 6 months schedule. The traditional financial measures of net present value (NPV) and internal rate of return (IRR) were used to assess the value of this improved time to market.

Net present value is defined as the total value in current rands, of a series of future cash flows (Creveling *et al.*, 2003). In this specific case, the series of cash flows will consist of an initial expenditure of R6.02 million in year zero (today's rand after investment tax credits) and the collection of net after tax profits in years 1 to 10. The future cash flows in years 1 through 10 will be discounted for the time value of money using MMC's cost of capital which is 12 percent.

In order to calculate the financial benefit associated with the expedited time to market the annual after tax profits associated with the commercialisation of the new AMT product was estimated using the following equation:

$$\text{After tax profit} = \text{Volume} \times \left(\text{Sales Price} - \frac{(\text{Cost Price per kg})}{\text{Yield}} \right) \times (1 - \text{Tax rate})$$

$$\text{After tax profit} = 7.5 \times \left(\text{R15 per kg} - \frac{(\text{R13 per kg})}{0.99} \right) \times (1 - 0.29) = \text{R9.95 million per year}$$

The net present value of the new AMT product is:

$$\text{NPV}_1 = -6.02\text{m} + \frac{(9.95)}{(1+0.12)^1} + \frac{(9.95)}{(1+0.12)^2} + \ldots + \frac{(9.95)}{(1+0.12)^{10}} = \text{R50.20 million}$$

The expected value of the new AMT product in current rand value is expected to be approximately R50.20 million which is equivalent to $6.92 million if the new product is commercialised on time and with all the current assumptions. A commercialisation delay of 3 months, given a finite product life cycle of 10 years will reduce the after tax revenues generated from the new AMT product in the first year to:

$$3\text{ month AMT product delay} = \frac{(9)}{(12)} \times R9.95\text{ million} = R7.46\text{ million}$$

Calculating the new NPV_2 for the AMT product with the 3 month delayed commercialisation timing yields the following results:

$$NPV_2 = -6.02m + \frac{(7.46)}{(1+0.10)^1} + \frac{(9.95)}{(1+0.10)^2} + \ldots + \frac{(9.95)}{(1+0.10)^{10}} = R47.98\text{ million}$$

$$\begin{aligned} \text{NPV difference} = NPV_1 - NPV_2 &= R50.20\text{ million} - R47.98\text{ million} \\ &= R2.22\text{ million} \end{aligned}$$

Direct comparison of the NPV's demonstrates that the cost of commercialisation delays can be significant; in this case it is approximately R2.22 million, equivalent to \$306 000 for a delay of only 3 months for the new AMT product.

The other financial measure used in assessing the value of the new AMT product was the internal rate of return (IRR). The IRR is defined as the cost of capital that will yield a net present value of zero (Creveling *et al.*, 2003). In the case of the delayed new AMT product commercialisation, the 3 month delay reduces the IRR of the project from 137% to 115%; again a relatively small delay of 3 months in bringing the new AMT product to market produces a significant reduction in IRR of 22%. Early customer involvement and proper execution of the DFSS methodology can help minimise the delays in new product commercialisation, it could reduce the time of the new product in the market and it could improve and enhance EBIT returns sooner.

5.2.1. One-way analysis of variance

Using the statistical analysis software, Minitab version 14, a one-way analysis of variance (ANOVA), was completed to test for the differences in means for EBIT between the various business improvement methodologies, i.e. (Six Sigma, DFSS, lean Sigma and replication Six Sigma projects from other CSG assets), currently being assessed at MMC at a pre-feasibility stage. In Fig. 5.2.1, N represents the total number of the different projects for the various business improvement methodologies from the other CSG assets which were sourced from the BCS system.

A 5% risk factor was chosen, i.e. the level of significance, alpha = 0.05. The null hypothesis (H_o) stated that the various business improvement methodologies do not affect EBIT. The statistical H_o stated that all the individual means for EBIT of the various business improvement methodologies are equal, i.e. H_o: $\mu_1 = \mu_2 = \mu_3 = \mu_4$.

The alternative hypothesis (H_a) stated that the various business improvement methodologies do have an effect on EBIT. The statistical H_a stated that the individual means for EBIT of the various business improvement methodologies are not equal, i.e. H_a: $\mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4$.

One-way ANOVA: EBIT versus Business Improvement Methodology

Source	DF	SS	MS	F	P
Improvement Methodology	3	4549	1516	10.31	0.000
Error	36	5294	147		
Total	39	9843			

S = 12.13   R-Sq = 46.22%   R-Sq (adj) = 41.74%

```
                                        Individual 95% CIs for Mean
                                        based on pooled Standard deviation

Level             N  Mean   StDev   ------+---------+---------+---------+---
DFSS              40 26.80  24.03                          (-----*------)
Lean Sigma        40  1.65   0.62   (-----*-----)
Replication Proj  40  4.60   3.17      (------*-----)
Six Sigma         40  0.89   0.49   (------*-----)
                                    ------+---------+---------+---------+---
                                          0        12        24        36
```

Pooled Standard Deviation = 12.13

Figure 5.2.1: One-way analysis of variance for EBIT between the various business improvement methodologies at MMC

The results of the ANOVA analysis illustrated in Figure 5.2.1 concluded, with a 95% statistical confidence that the null hypothesis must be rejected and the alternate hypothesis must be accepted, i.e. there is a significant difference in the means for EBIT between the various business improvement methodologies. The results of the ANOVA analysis illustrated in Figure 5.2.1 have illustrated that the DFSS business improvement methodology would yield the highest EBIT returns compared to the other improvement methodologies at MMC.

5.3. The strategic plan

The BHP Billiton's strategic plan sets out eight imperatives, one of which is to operate excellently. This OE imperative challenges the BHPB holding companies to (Internet 2):

- Deliver on benefits equating to 4.4 percent of total costs with an achievement of more than US$1 billion in annual benefits by the end of FY 2009.
- Increase the EBIT and free cash flow with the aim of achieving a return on capital of more than 15 per cent by FY 2009 (internet 2).

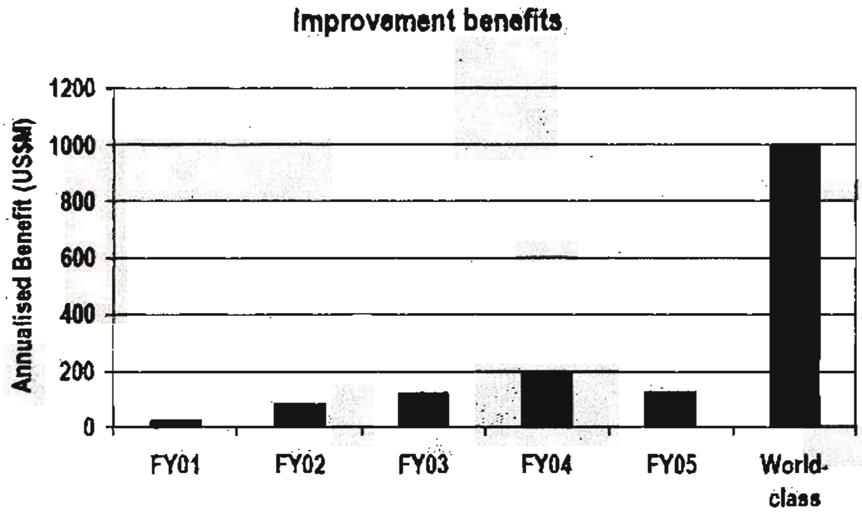

Figure 5.3.1: Six Sigma total improvement benefits reported to BHPB

Figure 5.3.1 represents the Six Sigma improvement benefits reported for years 2001 to 2005 for all the BHPB CSG's. The current world class benchmark for the Six Sigma annualised improvement benefits is $1 billion. None of the BHPB CSG's reported any DFSS annualised improvement benefits. After 2004, the improvement benefits reported by most of the CSG assets have slowed down and there was a downward trend in the reporting of the annualised improvement benefits for most of the CSG's (French, 2005).

Metric	World Class	BHPB June 2002	BHPB June 2003	BHPB June 2004	BHPB March 2005
Projects per year per active Black Belt	3.5	0.8	1.5	2.1	[illegible]
Projects per year per active Green Belt	2.0			0.9	1.1
Full-time Black Belts as a % of Workforce	1%	0.1%	0.2%	0.3%	0.3%
Active Green Belts as a % of Workforce	5%	0.0%	0.4%	0.8%	0.6%
EBIT Improvement as % of Total Revenue	3.0%	0.6%	1.0%	[illegible]	[illegible]

<25% of Benchmark	25-50% of Benchmark	50-75% of Benchmark	[illegible]

Operating Excellence BHP Billiton

6σ Six Sigma

Table 5.3.1: BHPB Six Sigma metrics

Table 5.3.1 highlights that BHPB have not reached the world class benchmark for Six Sigma improvement projects. The scorecard results reported for the years 2002 to 2005 shows that there was a marginal improvement in the EBIT improvement benefits declared, however, the world class benefit benchmark of 3,0% was not attained. The table also shows that at BHPB there is variation in the number of the full time equivalent active Black Belts and Green Belts in comparison to the world class benchmarks. MMC has only one Black Belt working full time on Six Sigma projects compared to a resource budget of 5 black belts that is required to be world class (French, 2005).

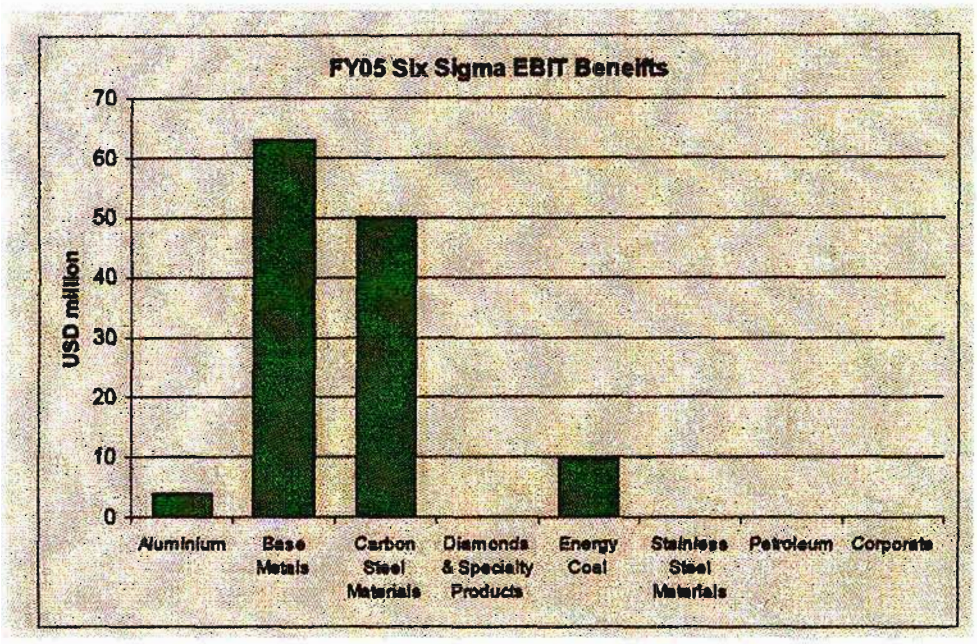

Figure 5.3.2: Six Sigma EBIT benefits per CSG

Figure 5.3.2 shows that there is variation in achieving and reporting annualised benefits in the different customer sector groups. Some of the CSG's reported no annualised improvement benefits. MMC is positioned under the Carbon Steel Materials CSG and reported only $0.65 million in the Six Sigma improvement benefits for FY 2005 (French, 2005).

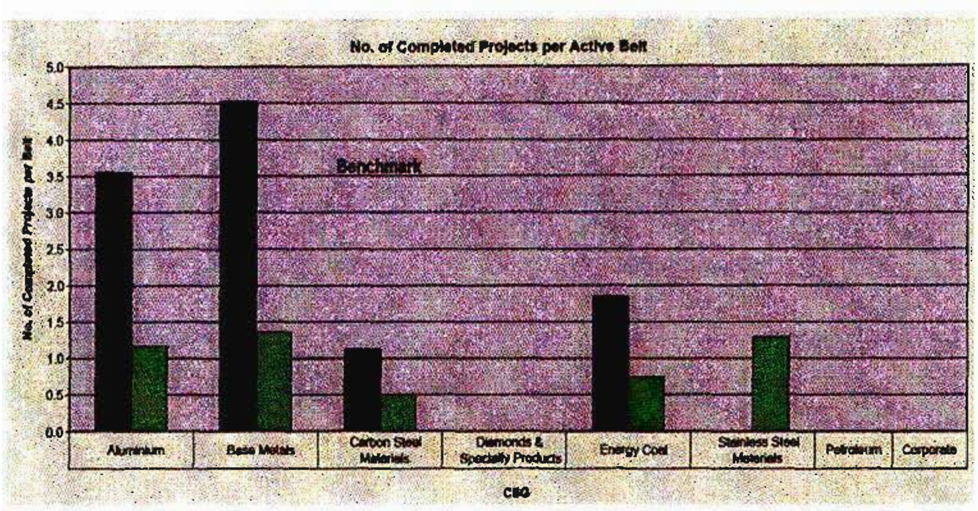

Figure 5.3.3: Number of Black Belt and Green Belt projects completed.

Figure 5.3.3 illustrates that there is variation in the completion of both Black Belt and Green Belt Six Sigma improvement projects for the different BHPB customer sector groups. None of the CSG's has declared any DFSS improvements projects (French, 2005).

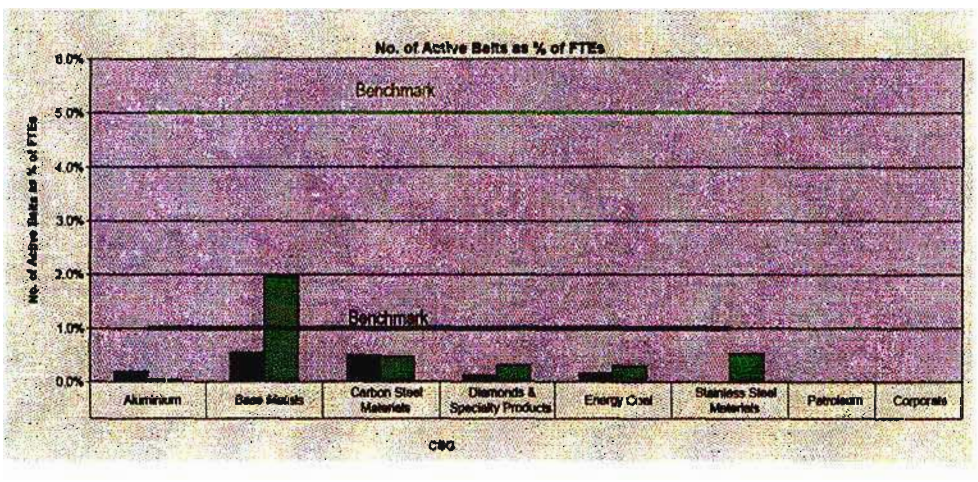

Figure 5.3.4: Number of active belts as % of Full Time Equivalents

Figure 5.3.4 shows that there is variation across all the BHPB customer sector groups in dedicating resources for the completion of Six Sigma improvement projects. None of the BHPB CSG's has reached the benchmark of dedicating 1% and 5% of the workforce to full time Black Belt and Green Belt coaches respectively (French, 2005).

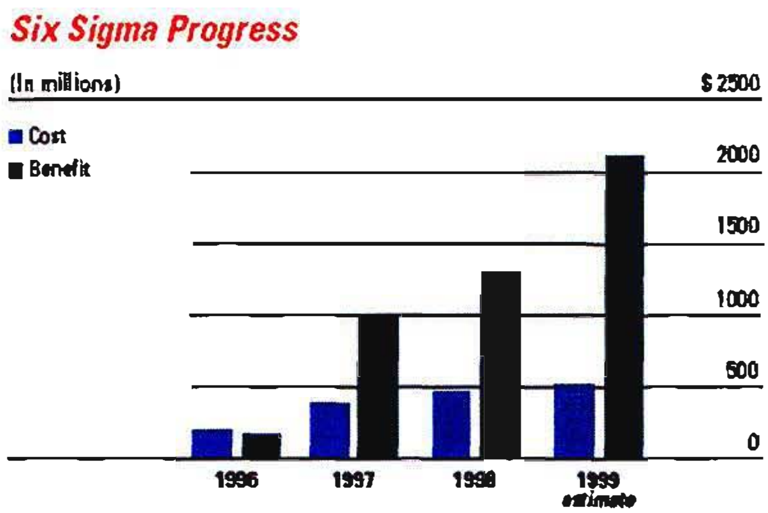

Figure 5.3.5: Six Sigma benefits and costs for General Electric. (Source: Internet 7)

General Electric, who implemented the Six Sigma programme in 1996, revealed company wide savings of more than $2.0 billion in 1999 as illustrated in Figure 5.3.5 (Anthony and Banuelas, 2002), however, these business improvement benefits also included the DFSS projects. Comparing the performance of the BHPB Six Sigma programme with the results being achieved by other companies like G.E., it is clear that, while BHPB have achieved reasonable results, the opportunities for further improvement and the replication of results can be enhanced to meet world class benchmarks with the implementation of the DFSS methodology in the BHPB existing OE programme.

5.4. Findings

The following are the key findings that emerge out of this dissertation.

It was shown that the DFSS methodology at MMC captures and enhances the voice of the customer early in the new AMT product development process and the risks of producing a product that will not meet customer expectations are minimised.

The use of the DFSS methodology within the new AMT product development process also results in improved time to market, minimisation of design rework and the elimination of product waste.

The primary key finding during this research was that none of BHPB CSG's are reporting any DFSS annualised benefits and in order for BHPB to reach the world class benchmark, the DFSS annualised benefits need to also be reported. Reporting DFSS annualised benefits could bring definable value to new product commercialisation and it would thus enhance the BHPB financial success metrics in achieving the $1 billion annualised improvement benefits benchmark objective for financial year 2009 or sooner. The adoption of DFSS may be a reinforcing factor for BHPB in identifying a need to increase the effectiveness of its existing annualised benefits financial metric as

DFSS promotes enhanced financials on new products, processes and services and also it increases the organisational learning in general, and specifically on the use of quality and project management tools.

There is variation in the current Six Sigma deployment programme in all the customer sector groups. None of the customer sector groups can disclose that they have leading practices in their Six Sigma programme. Most of the CSG's disclosed that their Six Sigma growth has slowed down and 98% of the assets had no knowledge of the DFSS methodology at their site. The majority of the senior leadership within the CSG's have not been trained in the Six Sigma methodology.

There is variation in the existing amount of annualised financial benefits reported for Six Sigma improvements within the BHPB customer sector groups. There is variation in the amount of Black Belts and Green Belts that were trained and whom are working full time on the Six Sigma continuous improvement projects. There is variation in the number of Black Belt and Green Belt projects being completed within all the BHPB customer sector groups. The Six Sigma results within BHPB are less than 20% of benchmark performance.

In terms of results, the benchmark performance for Six Sigma programmes is considered to be the EBIT benefit that represents 4.4% of total costs. In FY05, it was reported that the Six Sigma benefits was US$126M which represents 0.7% of total costs.

The main drivers of Six Sigma results are the Black Belts and Green Belts. The results of the Six Sigma programme within BHPB are falling short of the benchmark in this area. Leading practice companies achieve Black Belt and Green Belt densities of 1% and 5% of full time equivalents employed respectively. Within BHPB, these numbers are 0.3% and 0.6% respectively.

The financial results for the annualised improvement benefits have not been achieved to date and the BHPB continuous improvement financial scorecard expectations were not met. The corporate team's alignment between Six Sigma and other existing initiatives like DFSS and lean Sigma do not exist. However, strategic planning has proved to be a key factor for identifying that continuous business improvement initiatives are critical for enhanced and continuous financial growth.

5.5. Conclusion

This chapter discussed the results of the financial benefits of the DFSS project for the proposed new AMT product currently being commercialised at MMC. Research findings shed light on the need to implement a strategy for DFSS at MMC and BHPB. The next chapter deals with the conclusions, recommendations and a strategic implementation plan emanating from the study.

Chapter 6

CONCLUSION AND RECOMMENDATIONS

6.1. Introduction

This chapter provides the conclusion and the recommendations for MMC and BHPB based on the evaluation of the DFSS case study. Since recommendations are of no use without a plan for the implementation, this chapter also highlights such an action plan.

6.2. Conclusions

The following are the key conclusions that emerged out of this dissertation.

- The use of the DFSS methodology for a new product design at MMC has a positive effect on a new products financial performance; it reduces the time to market the new product, it generates shareholder value, it enhances customer value and satisfies the market place.
- A commercialisation delay of three months, given a finite product life cycle of 10 years in implementing a DFSS project reduces EBIT, NPV and IRR significantly for a new product at MMC.

- The DFSS business improvement methodology yielded the highest EBIT returns compared to the other business improvement methodologies at MMC and BHPB respectively.
- DFSS would therefore have a positive effect on the BHPB FY 2009 strategic objectives in achieving the FY09 objective of $1 billion in annualised business improvement benefits.

6.3. Recommendations

From the preceding discussions, the following recommendations highlighting the effectiveness of DFSS within MMC and BHPB emerge.

6.3.1. The strategic plan

DFSS should be linked to the BHPB's BE strategic plan and the growth goals initiative to stimulate opportunities in new products, processes and services development. DFSS is more than a quality initiative; it is a structured approach to enhancing the BHPB business strategy and delivering against the corporate strategic objectives. The BHPB corporate strategic objectives must be linked to the core DFSS business processes and the management of BHPB and it's CSG's need to identify the gaps between the current and the desired future state. DFSS projects should be chosen to close these gaps for new products, processes and services or when a process improvement needs such radical change then a redesign is needed.

An integrated DFSS process will allow BHPB to identify critical leverage points for improving the overall financial performance in achieving the FY09 objective of $1 billion in annualised improvement benefits. A strategic planning system must be developed to translate the executable action plans with related performance measurements. It needs to include the applicable technical, human and financial resources to support the implementation of executable business action plans.

BHPB needed to shift from bottom line operational Six Sigma projects to top line DFSS projects by focussing on projects to initiate market share by opening new markets with new designs where the price could be established, obtaining market share in new markets with an existing design at current market prices and improving margins and revenue growth in existing markets with new product designs.

6.3.2. Benchmarking

A comprehensive global competitive benchmarking system must be developed to collect the existing market and competitors' information on new products, processes and services. The process of benchmarking information collection needs to be evaluated to ensure its effectiveness. When the critical processes and outcome measures are benchmarked, the BHPB CSG's with the best performance will have attained leading practices. These leading practices must be shared with all the other operating assets within the BHPB CSG's.

6.3.3. DFSS training and deployment

Top management leadership and commitment are essential to DFSS success. Top management should act as key driver in the DFSS continuous improvement implementation, communicate to employees about DFSS organisational goals and establish an environment for supporting organisational and employee learning. The Six Sigma training system should provide continuous DFSS courses to employees for equipping them with quality related knowledge of using the DFSS methodologies and tools. All CSG's should train and develop the required 1% and 5% of Black Belts and Green Belts respectively.

6.3.4. External audits

A DFSS audit should be conducted in all the BHPB CSG's to assess and evaluate the number of DFSS projects that can enhance the financial measures of success for new products, processes and services. These projects should be quantified and translated into design scorecards to achieve the enhanced financial value.

6.3.5. Replication

Completed improvement projects can be replicated more easily and quickly than improvements developed from scratch and therefore, should be actively promoted. The purpose of replication is to multiply the value of each asset's leading practices within all the customer sector groups in BHP Billiton. All the high value improvement projects within the BCS system needs to filtered and communicated to all the CSG assets during audits, site visits, conferences and net meetings. This will enhance the EBIT improvements and finally impact positively on the FY09 objective to reach the $1 billion in annualised improvement benefits benchmark.

An optimised designed replication management system is critical to DFSS success and a replication process needs to be established to fulfil the needs of projects and improvements that need to be replicated.

6.3.6. Benefits capture system

The benefits capture system should be upgraded to collect the DFSS EBIT performance measures in order to monitor and track the value added projects to benefit the FY09 objectives. All the CSG and asset teams need to select the high value DFSS projects, drive the programmes and ensure the project completion rates within BCS.

6.3.7. Change management

DFSS should be seen as a change management tool used for radical and breakthrough innovation for new products, processes and services design at BHPB. The consensus is that BHPB has not fully embraced DFSS in its BE strategy, a commitment and acceptance strategy is needed within the corporate leadership team from the top of the organisation.

A DFSS rollout strategy should be developed. The best business decisions are useless if the actual implementation is flawed, hence, the importance of a good rollout strategy, a plan to ensure adept implementation of the DFSS methodology in the BE strategy plan.

Statistical process control and process management systems must be implemented to measure, monitor and manage the performance of the DFSS process in terms of customer specifications. Customer specific dash boards should be generated and reviewed internally to determine the areas where improvement efforts are needed.

6.4. Proposed implementation action plan

Revise the CSG strategic plan to incorporate DFSS methodology (complete by end March 2007).

DFSS audit in all the customer sector groups (completed by April 2007).

DFSS scorecards quantified (complete by May 2007).

DFSS training and deployment (complete by July 2007).

6.5. Areas for further study

DFSS needs to be integrated into BHPB's existing project management and Six Sigma toolkits and methodologies.

The current systems hierarchy within BHPB which includes the Benefits Capture System and the Sixnet system needs to be streamlined to accommodate the seamless integration of the different toolkits and methodologies of Six Sigma, DFSS and lean Sigma.

Financial tracking of DFSS projects need to be implemented in the BCS system.

Six Sigma and DFSS tools need to be matched to projects.

Increasing and improving linkage to and with customers, outlining the ways to ensure that the "voice of the customer" has impact in the design for Six Sigma projects.

6.6. Conclusion

This chapter discussed the conclusions, the recommendations and a strategic implementation plan emanating from the research undertaken at MMC and BHPB.

DFSS is the most effective business improvement methodology for realising the full benefits of Six Sigma capability in design. It ensures that the concepts and principles of the Six Sigma process are applied at the design and development stages for a new product, process and service design for enhanced customer satisfaction, improved long term profitability and profit margin, increased new process and product reliability. When DFSS is successfully applied, it proves to be a methodology of harnessing the best process design practices to achieve competitive advantage and business excellence.

BIBLIOGRAPHY

Adams, C. W., Gupta, P. and Wilson, Jr., C. E. (2003). Six Sigma Deployment. Boston: Butterworth-Heinemann.

Alloway, R.M. (1977). Research and Thesis Writing Using Comparative Cases. Stockholm: Institute of International Business.

Altshuller, G. S. (1984). Creativity as an Exact Science - The Theory of the Solution of Inventive Problems. Luxemburg: Gordon and Breach.

Anglin, M. (2003). Operating Excellence Annual Review 2003. Melbourne: BHP Billiton Operating Excellence Group.

Antony, J. (2004). Some Pros and Cons of Six Sigma: An Academic Perspective. *The TQM Magazine*, Vol. 16, No. 4, pp. 303-306.

Anthony, J. and Banuelas, R. (2002). Key Ingredients for the Effective Implementation of Six Sigma Program. *Measuring Business Excellence*, Vol. 6, No. 4, pp. 20-27.

Barney, M. (2002). Motorola's Second Generation. *Six Sigma Forum Magazine 1*, No.3. May 2002, pp. 13-17.

Baskerville, R. and Pries-Heje, J. (1999). Grounded Action Research: A Method for Understanding IT in Practice. *Accounting Management and Information Technologies*, Vol. 9, No. 1, pp. 1-23.

Baskerville, R. and Wood-Harper, T. (1996). A Critical Perspective on Action Research as a Method for Information Systems Research. *Journal of Information Technology*, Vol. 11, No. 3, pp. 235-46.

Bertels, T. (2003). Six Sigma Leadership Handbook. Ed. New York: John Wiley & Sons.

BHP Billiton HSEC Policy and Guidelines. (2004)

Bowen, H.K. and Spear, S. (1999). Decoding the DNA of the Toyota Production System. *Harvard Business Review,* (September-October, 1999), 97-98.

Breyfogle, F.W., Cupello, J.M. and Meadows, B. (2001). Managing Six Sigma: A Practical Guide to Understanding, Assessing and Implementing the Strategy That Yields Bottom-Line Success. New York: John Wiley and Sons.

Brue, G. (2002). Six Sigma for Managers. New York: McGraw Hill.

Brue, G. and Launsby, R. (2003), Design for Six Sigma. New York: McGraw Hill.

Chowdhury, S. (2004). Design for Six Sigma: The Revolutionary Process for Achieving Extraordinary Profits. New York: Prentice Hall.

Cooper, D.R. and Schindler, P.S. (2003). Business Research Methods. New York: McGraw Hill.

Coghlan, D. and Brannick, T. (2001). Doing Action Research in Your Own Organisation. London: Sage.

Coughlan, P. and Coghlan, D. (2002). Action Research for Operations Management. *International Journal of Operations & Production Management*, Vol. 22, No. 2, pp. 220-40.

Creveling, C.M., Slutsky, J.L. and Antis, D. (2003). Design for Six Sigma in Technology and Product Development. New Jersey: Prentice Hall.

Dambolena, I. and Rao, A. (1994). What is Six Sigma Anyway? *Quality*, Vol. 33, No. 11, pp. 10-10.

Dangayach, G. S. and Desmukh, S. G. (2001). Manufacturing Strategy: Literature Review and Some Issues. *International Journal of Operations & Production Management*, Vol. 21, No. 7, pp. 884-933.

Denton, D. K. (1991). Lessons on Competitiveness: Motorola's Approach. *Production and Inventory Management Journal*, Vol. 32, No. 3, pp. 22-25.

Eckes, G. (2001a). The Six Sigma Revolution: How General Electric and Others Turned Process into Profits. New York: John Wiley and Sons.

Eckes, G. (2001b). Making Six Sigma Last: Managing the Balance Between Cultural and Technical Change. New York: John Wiley and Sons.

French, S. (2005). Business Excellence and the Challenge for Six Sigma. Global Co-ordinators Workshop, 7 September 2005, Santiago: BHPB Billiton Operating Excellence Group.

General Electric. (2000). Letter to Share Owners, GE Annual Report, 1.

Ghauri, P. and Gronhaug, K. (2002). Research Methods in Business Studies. London: Prentice Hall.

Goh, T. N. (2002). The Role of Statistical Design of Experiments in Six Sigma: Perspectives of a Practitioner. *Quality Engineering*, Vol. 14, No. 4, pp. 659-672.

Hahn, G. J., Hill, W. J., Hoerl, R. W. and Zinkgraf, S. A. (1999). The Impact of Six Sigma Improvement – A Glimpse into the Future of Statistics. *The American Statistician*, Vol. 53, No. 3, pp. 208-215.

Harry, M.J. (1998). Six Sigma: A Breakthrough Strategy for Profitability. *Quality Progress*, Vol. 31, No. 5, pp. 60-64.

Harry, M.J. and Schroeder, R. (2000). Six Sigma: The Breakthrough Management Strategy Revolutionizing the World's Top Corporations. New York: Doubleday.

Hendricks, C. A. and Kelbaugh, R. L. (1998). Implementing Six Sigma at GE. *The Journal for Quality and Participation*, Vol. 21, No. 4, pp. 48-53.

Hoerl, R.W. (1998). Six Sigma and the Future of the Quality Profession. *Quality Progress*, Vol. 31, No. 6, pp. 35-42.

Hoerl, R. W., Montgomery, D. C., Lawson, C. and Molnau, W. E. (2001). Six Sigma Black Belts: What Do They Need to Know? *Journal of Quality Technology*, Vol. 33, No. 4, pp. 391-406.

Hult, M. and Lennung, S. (1980). Towards a Definition of Action Research: A Note and Bibliography. *Journal of Management Studies*, Vol. 17 No. 2, pp. 241-50.

Hussey, J. and Hussey, R. (1997). Business Research: A Practical Guide for Undergraduate and Postgraduate Students. New York: Palgrave.

Ishikawa, K. (1985). What is Total Quality Control? The Japanese Way. Englewood Cliffs, New Jersey: Prentice Hall.

Juran, J.M. and Gryna, F.M. (1993). Quality Planning and Analysis, 3rd Ed. New York: McGraw Hill.

Kaynak, H. (2003). The Relationship Between Total Quality Management Practices and Their Effects on Firm Performance. *Journal of Operations Management*, Vol. 21, No. 4, pp. 405-435.

Kessler, R.M. and Padula, A.D. (2005). The Implementation of Six Sigma in Manufacturing Organisations: Motivations and Results Achieved. Sixteenth Annual Conference of the Production and Operations Management Society, Chicago, IL, April 29 – May 2, 2005. Universidade Federal do Rio Grande do Sul. Brazil.

Kume, H., (Ed.). 1985. Statistical Methods for Quality Improvement (Loftus J.: translator), The Association for Overseas Technical Scholarship, Tokyo, Japan.

Kume, H. (1995). Management by quality (Loftus, J.: translator). 3A Corporation, Tokyo, Japan.

Linderman, K., Schroeder, R.G., Zaheer, S. and Choo, A.S. (2003). Six Sigma: A Goal Theoretic Perspective. *Journal of Operations Management*, Vol. 21, No. 2, pp. 193-203.

Lucier, G.T. and Seshadri, S. (2001). GE Takes Six Sigma Beyond the Bottom Line. *Strategic Finance*, Vol. 82, Issue 11, pp. 40-47.

McNiff, J. (1998). Action Research: Principles and Practices. Basingstoke: Macmillan Education.

Malhotra, M. K. and Grover, V. (1998). An Assessment of Survey Research in POM: from Constructs to Theory. *Journal of Operations Management*, Vol. 16, pp. 407-425.

MMC Management Information System. (2005).

MMC: Project Charter. (2005).

Montgomery, D.C. (2001). Introduction to Statistical Quality Control, 4th Edition. New York: John Wiley and Sons.

Pande, P.S., Neuman, R.P. and Cavanagh, R.R. (2000). The Six Sigma Way: How GE, Motorola and Other Top Companies Are Honing Their Performance. New York: McGraw Hill.

Pande, P.S., Neuman, R.P. and Cavanagh, R.R. (2002). The Six Sigma Way Team Field Book. New York: McGraw Hill.

Pande, P. and Holpp, L. (2002). What is Six Sigma? New York: McGraw Hill.

Picard, D. (2004). The Design for Six Sigma Memory Jogger. New Hampshire: Goal OPC.

Pruitt, D.W., Van Tiem, D.M. and Doyle, T.R. (2002). Six Sigma: Product Improvement and Culture Change at Auto Alliance. *The Engineering Society for Advancing Mobility Land Sea Air and Space*, 2002-01-07, 66.

Pyzdek, T. (2003). The Six Sigma Handbook. New York: McGraw Hill.

Reed, R., Lemak, D. J. and Mero, N. P. (2000). Total Quality Management and Sustainable Competitive Advantage. *Journal of Quality Management*, 55-26.

Saunders, M., Lewis, P. and Thornhill, A. (2003). Research Methods for Business Students. 3rd Ed. Harlow: Prentice Hall.

Sauer, P. (2001). Six Sigma and the Bottom Line. *Chemical Market Reporter*, Vol. 260, Issue 3, pp. 10-12.

Schneiderman, A.M. (2000 modified 2003). Question: When is Six Sigma not Six Sigma? Answer: When it's the Six Sigma Metric! www.schneiderman.com.

Shewhart, W.A. (1931). Economic Control of Quality of Manufactured Product. New York: D. Van Nostrand.

Shewhart, W.A. (1939). Statistical Method from the Viewpoint of Quality Control. Graduate School of the Department of Agriculture, Washington, DC.

Slack, N. (1992). The Manufacturing Advantage: Achieving Competitive Manufacturing Operations. London: Mercury Books.

Smith, J. (2004). Operating Excellence Induction booklet: Guidelines, Policies and Procedures. Vol. 1, October 2004. Melbourne: BHP Billiton Operating Excellence Group.

Susman, G. and Evered, R. (1978). An Assessment of the Scientific Merits of Action Research. Administrative Science Quarterly, Vol. 23, No. 4, pp. 582-603.

Tennant, G. (2001), Six Sigma: SPC and TQM in Manufacturing and Services. New Hampshire: Gower Publishing Company.

Westbrook, R. (1994). Action Research: a New Paradigm for Research in Production and Operations Management, *International Joumal of Operations & Production Management*, Vol. 15, No. 12, pp. 6-20.

Wheelwright, S. C. and Hayes, R. H. (1985). Competing Through Manufacturing. *Harvard Business Review*, 99-109, January - February.

Internet 1: (2007). *Company Overview.* [Online]. Available: http://www.bhpbilliton.com/bb/aboutus/companyoverview/ourprofile.jsp [4 July 2006]

Internet 2: (2007). *Six Sigma.* [Online]. Available: http://www.bhpbilliton.com/SixSigma/operatingexcellence.htm [1 August 2006]

Internet 3: Goodyear, C. (2006). *Company Overview.* [Online]. Available: http://www.bhpbilliton.com/bb/aboutus/charter.jsp [1 August 2006]

Internet 4: Goodyear, C. (2005). *Six Sigma.* [Online]. Available: http://www.operatingexcellence.bhpbilliton.net/bhpboe/SixSigma/index.htm [2 August 2006]

Internet 5: (2006). *Sigma Breakthrough Technologies*. [Online].
http://www.sbtionline.com/ourservices/growthexcellence/DFSS.php
[8 August 2006]

Internet 6: (2007). *Manganese Metal Company*. [Online].
http://www.mmc.co.za
[8 August 2006]

Internet 7: (2003). *General Electric*. [Online].
http://www.ge.com/SixSigma
[10 September 2006]

APPENDIX

RESEARCH OFFICE (GOVAN MBEKI CENTRE)
WESTVILLE CAMPUS
TELEPHONE NO.: 031 – 2603587
EMAIL: ximbap@ukzn.ac..za

UNIVERSITY OF
KWAZULU-NATAL

12 FEBRUARY 2007

MR. S DYMOND (203518439)
GRADUATE SCHOOL OF BUSINESS

Dear Mr. Dymond

ETHICAL CLEARANCE APPROVAL NUMBER: HSS/0004/07M

I wish to confirm that ethical clearance has been granted for the following project:

"An integrated design for six sigma strategy to a new product design in a global resources company"

Yours faithfully

....

MS. PHUMELELE XIMBA
RESEARCH OFFICE

cc. Faculty Officer (Christel Haddon)
cc. Supervisor (Mr. RM Challenor)