



**Assessing the influence of continuous
improvement on manufacturing performance
at a fertiliser company**

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ABSTRACT

Continuous improvement has been introduced to a fertiliser manufacturing company through a benchmarking exercise performed by senior management. The adoption and commitment of this improvement strategy, has remained optional for the production departments at the company. After 3 years of polarised deployment, the company seeks to understand the quantifiable benefit of continuous improvement on its manufacturing performance.

The effect of continuous improvement on manufacturing performance, within a South African fertiliser company, has not been studied to date. This concept, originating from the Japanese automobile assembly sector, has proven to yield significant benefits such as economies of scope as well as economies of scale in the automobile sector.

This study is based on the assessment of continuous improvement on manufacturing performance within the industrial sector in Sasolburg, South Africa. The objective of the study is to determine whether the implementation of continuous improvement resulted in a positive, negative or unchanged impact on manufacturing performance.

Conclusions on the influence of continuous improvement on manufacturing performance were made, based on the results of the quantitative study conducted. Recommendations were then proposed to the company in line with the results obtained.

Keywords: Continuous improvement, focused improvement, manufacturing performance, operational plant effectiveness.

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All praise is due to Allah (SWT), the most beneficent, the most merciful. For surely without your divine intervention and plan, none of this would be possible.

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LIST OF ABBREVIATIONS

Abbreviation	Description
FI	Focused improvement
NEGD	Non-equivalent group design
OPE	Overall Plant Effectiveness
TPM	Total Productive Maintenance
TQM	Total Quality Maintenance
UNIDO	United Nations Industrial Development Organisation

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CHAPTER 1

NATURE AND SCOPE OF STUDY

1.1. INTRODUCTION

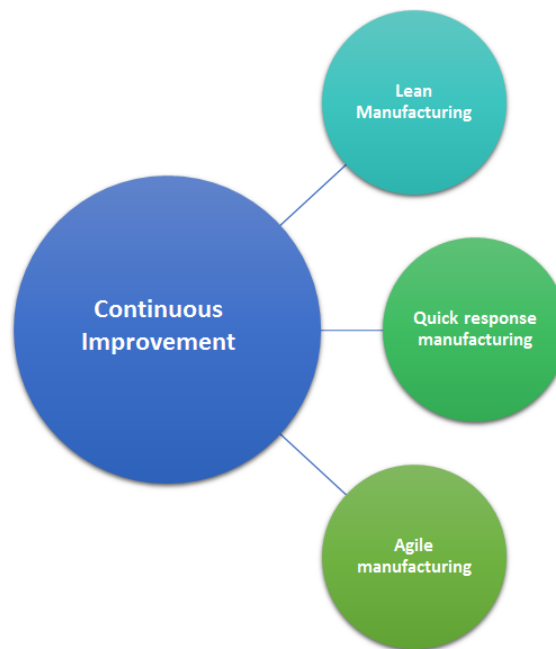
The main focus of this study relates to the concept of continuous improvement and its potential effect on manufacturing performance. The purpose of this chapter relates to the background and scope of the study undertaken. It will provide a brief introduction into continuous improvement, explain the problem statement and research objectives, as well as the scope and limitations of the study carried out. Chapter 1 will additionally explain the research methodology followed during the study performed.

1.2. CONTINUOUS IMPROVEMENT

Industrial firms are strategically deploying continuous improvement programmes at their manufacturing facilities, in an attempt to increase their productivity and their global competitiveness. Continuous improvement is generally defined as a methodology for recognising opportunities for work optimisation and waste reduction (Leankit, 2017). It is usually implemented in manufacturing industries through a number of programmes such as Lean, Six Sigma, Lean-Six Sigma, Total Quality Management (TQM) and Total Productive Maintenance (TPM), to name but a few.

According to Filho and Uzsoy (2014:3014), continuous improvement programmes are categorised into three distinct paradigms namely lean manufacturing, quick response manufacturing and agile manufacturing. This is depicted in figure 1.1 below.

Figure 1.1: The continuous improvement paradigms



Lean manufacturing is solely aimed at identifying, reducing and or eliminating waste in a business process. The waste may be in the form of time, cost and or rework. The study conducted, pertains to the effect of the implementation of lean manufacturing concepts on manufacturing performance.

Quick response manufacturing targets the reduction of the manufacturing time through streamlining of activity lead times on the manufacturing critical path. It focuses the organisation's resources to eliminate non-value added work and improve product turnaround time.

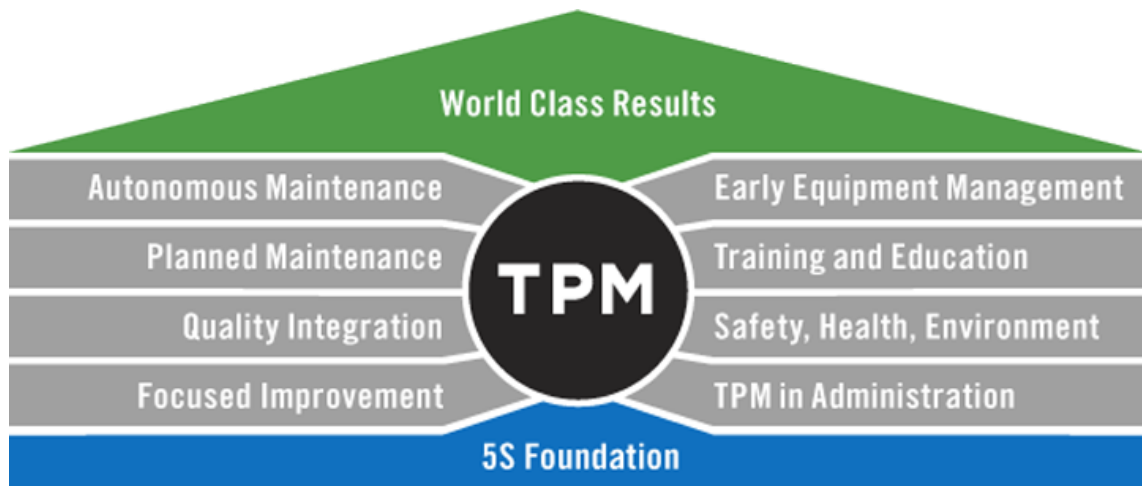
Agile manufacturing, unlike lean and quick response manufacturing, is aimed at placing more emphasis on ensuring a swift response to changing customer demand. It allows the organisation to evolve into becoming a more flexible and adaptable operation, which produces personalised products and services on demand.

Amongst the numerous lean manufacturing continuous improvement programmes is Total Productive Maintenance or TPM. The TPM programme was first piloted

by Japanese automobile manufacturers from which its success has gone onto spread across various industrial manufacturing facilities. TPM unlocks hidden potential by yielding tangible results, transforming the plant environment and upskilling operational and maintenance staff. It has been described as a well-rounded methodology to improving equipment maintenance aimed at achieving ideal production (Lean Production, 2017).

Focused improvement (FI) is a core pillar or activity set which falls under the TPM program umbrella of initiatives. This is depicted in figure 1.2 below. It is designed to minimise or eliminate losses highlighted to the manufacturing facility in operational, maintenance and scheduling disciplines. It consists of teams working closely together, striving to achieve incremental improvements in manufacturing performance (Lean Production, 2017). Focused improvement is an objective structured strategic approach, which drives improvement and innovation within the manufacturing operation.

Figure 1.2: The traditional TPM model



Source: Lean Production

As previously mentioned, there are other objective structured continuous improvement approach alternatives with which industrial firms may select. However, in contrast to these structured approaches, there is also the traditional

subjective approach to driving improvement within a manufacturing facility, which is based on experience, opinion strength and managerial influence.

Industrial manufacturing firms have no standard approach for implementing improvement or innovation programmes at their facilities, and the resulting strategy is often left up to the culture of the company in question to decide on this journey.

1.3. PROBLEM STATEMENT

A South African fertiliser manufacturing company has implemented a continuous improvement programme, in the form of TPM's FI, at some of its operations over a period of approximately three years and has intentionally left the remaining operations to continue with the traditional subjective approach to improvement. It has therefore requested this study to assess the effect of the implementation of the continuous improvement programme, FI, on manufacturing performance, as compared to the other production units which still used the traditional subjective approach.

The problem to be investigated in this study is whether the South African fertiliser manufacturing company in question, should continue with the investment of a blanket roll-out strategy of implementing continuous improvement activities, in the form of FI, at all of its operational facilities, or revert back to the traditional subjective approach to implement improvement and innovation, thereby re-directing critical resources elsewhere within the organisation.

Alternatively put, the study tests the impact (positive, negative or unchanged) of the implemented continuous improvement programme, FI, on manufacturing performance as compared to the subjective approach traditionally executed. The purpose of the study is to present the company with a strategic direction arising out of the investigation.

The core research question to be answered would be: has the implementation of continuous improvement at a South African fertiliser manufacturing plant, resulted in a significant positive impact on manufacturing performance?

The study additionally benefits the operational management field, as the effect of focused improvement on manufacturing performance in an industrial company, from a South African context, could not be found in published literature to date from the literature review conducted.

1.4. OBJECTIVES OF THE STUDY

1.4.1. Primary objectives

The primary research objectives of the study were to:

- I. analyse the objective approach to improvement and innovation, which is the effect of continuous improvement on manufacturing performance within a South African fertiliser company
- II. analyse the traditional subjective approach to improvement and innovation on manufacturing performance within a South African fertiliser company
- III. compare the objective approach and subjective approach and make a suitable recommendation to the organisation in terms of their improvement strategy

1.5. SCOPE OF THE STUDY

1.5.1. Field of study

The study falls within the operational management sphere of business management with specific reference to industrial manufacturing and its measurement of performance.

1.5.2. Industry and location of study

The study falls within the fertiliser manufacturing industry within South Africa.

1.6. RESEARCH METHODOLOGY

The study has been conducted in two phases, namely a literature study and an experimental study. Six basic steps were adhered to, during the study conducted:

- Identifying a relevant research topic
- Defining the research problem
- Determining the nature of the study to be conducted
- Gathering the data from the study conducted
- Analysing and interpreting the data obtained
- Writing the report on the interpreted findings

1.6.1. Literature Review

The literature review, seeks to clarify the need for continuous improvement programmes in fertiliser manufacturing companies. It reviews the global economic market conditions as well as considers the fertiliser specific market conditions.

The literature review then recognises past research into continuous improvement programmes and innovation in manufacturing plants. It seeks to define focused improvement within the TPM programme, and also defines the key performance metrics which will be used within the study.

1.6.2. Experimental Study

1.6.2.1. Research Design

The study undertaken aims to investigate the effect, if any, of implementing continuous improvement on manufacturing performance, within a South African fertiliser company.

The study was quantitative in nature, as the readily available production data (availability, performance rate, and quality rate) was statistically analysed to determine the effect of continuous improvement on manufacturing performance within the company.

The intervention in this study, is the implementation of the focused improvement pillar of the TPM continuous improvement program. The concept of focused improvement was introduced in 2014, to the manufacturing company by senior management after conducting an international benchmarking exercise into various improvement strategies in industry. The concept of TPM and continuous improvement was met with mixed reactions at the manufacturing site. Due to the fact that TPM was not enforced but rather encouraged by senior management, it led to the polarisation of deployment across the manufacturing site.

Due to this polarisation effect, the study is based upon a group comparison, between a manufacturing department that did participate in the continuous

improvement program and a manufacturing department that did not participate in the program.

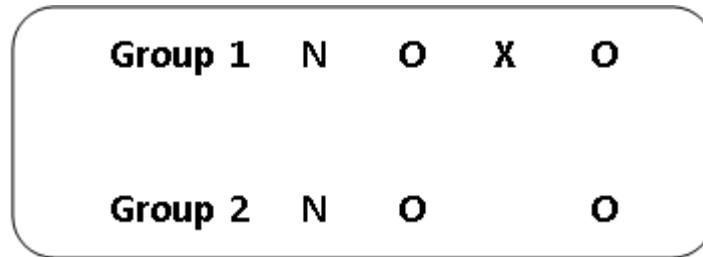
Manufacturing departments were not forced to deploy the continuous improvement concept, and were allowed to implement as they so wished. Thus, the groups in the study occurred naturally and was non-randomised by the researcher. A non-randomised study with intervention, is referred to as a quasi-experimental study.

The groups in this study that did elect to participate in the focused improvement program would be the intervention group, while those that did not elect to participate in the deployment of the continuous improvement program would be the control group.

The quasi-experimental study was longitudinal in nature as the data in question (availability, performance rate, and quality rate) represented the manufacturing performance over a period 45 months. The time interval between the data points were 30 days.

The research design thus took the form of a non-equivalent group design (NEGD). An example of NEGD is depicted in figure 1.3 below. In the below figure, N represents the non-randomisation, O the observation, and X represents the intervention.

Figure 1.3: Graphical representation of the proposed non-equivalent group design in quasi-experimental research



Source: Research methods knowledge base

1.6.2.2. Study population

The fact that the manufacturing departments elected to implement the focused improvement pillar of TPM as they so wished, was clear that the sampling strategy employed was convenience sampling. Bryman *et al.* (2015:178) define a convenience sample as “one that is available to the researcher by virtue of its accessibility.”

It would have been impractical and too costly for the researcher to move to another industrial fertiliser complex in South Africa, with the intention of attempting to complete the study through a true randomisation of participating groups.

The unit of analysis was situated in Sasolburg, South Africa. The information about the unit of analysis will remain within the private domain. The unit of analysis was most suitable as it directly answered the core research question posed by the chemical fertiliser manufacturer itself. There has not been any prior studies completed with regards to the successful deployment of continuous improvement at a fertiliser manufacturing company in South Africa.

An alternative unit of analysis, such as other international chemical fertiliser manufacturing plants, may not be necessarily relevant to this study, as the results could not easily be generalised due to the cultural impact of successfully implementing continuous improvement within a South African context.

1.6.2.3. Data collection

The production data (availability, performance rate, and quality rate) required to calculate the Overall Plant Effectiveness (OPE) of both the intervention group and the control group, was collected and downloaded off the company's management execution system. This system records the required units of data, and stores it within a data historian from which it is easily accessible. The data instrument may be seen in Appendix A and B.

The data was internally reliable, as the availability, performance rate and quality rate are consistent and independent of each other. Each of these constructs are defined in Chapter 2. The measurement validity will also be confirmed during the study by the evaluation of Cronbach's alpha in Chapter 3.

The validity of the data measurement has been confirmed by relevant authors in the field of operational management in industry. Both Ahuja *et al.* (2007:341) and Suzuki (1994:30) confirm the use of availability, performance rate and quality rate to determine the OPE. Furthermore, both sources regard OPE as an acceptable measure of manufacturing performance.

1.6.2.4. Data analysis

For the study undertaken, there is one dependent variable and one independent variable. The independent variable, being whether focused improvement is deployed or not (which is the intervention in the study) is categorical in nature and the dependent variable being the differential OPE. The differential OPE data which is continuous in nature, will be aggregated and statistically analysed prior, during and post intervention.

1.7. LIMITATIONS OF THE STUDY

The scope of the study was limited to the South African fertiliser manufacturing company located in Sasolburg within the Free State province of South Africa. No other companies or organisations were included within the study.

Furthermore, the study of the effect the continuous improvement programme, FI, on manufacturing performance, was limited to the industrial operational facilities at the abovementioned company, which are actual production units, and did not encompass supporting departments or any other service departments within the organisation. The results of the study will thus apply to the operational manufacturing facilities at the abovementioned company only.

CHAPTER 2

LITERATURE REVIEW

2.1. THE GLOBAL ECONOMIC COMMUNITY

In the aftermath of the global financial crisis of 2008, competitiveness has become increasingly important to manufacturing firms, in order to create and sustain value in the global marketplace (Voulgaris & Lemonakis, 2014:191). Multinational and domestic manufacturing organisations now find themselves under pressure to survive the long term effects of this crisis, while still being able to create growth and wealth for shareholders (Guimbert & Oostendorp, 2016:87).

In addition to the financial crisis, the interconnectedness of countries through business trade agreements, together with technological developments resulting in the relative ease of sourcing manufactured goods across continents through high speed digital connectivity, have meant that manufacturing organisations compete for the same customer locally, at import parity prices. Gone are the days where local producers dictate the price of manufactured industrial goods at local markets, except where government influence is exerted through policy intervention.

Similar sentiments were reported in the 2016 United Nations Industrial Development Organization (UNIDO) report into emerging trends of global manufacturing industries. The report states that “there is growing recognition that business as usual is not an option if national manufacturing competitiveness is to be achieved and sustained in the future” (UNIDO, 2016:v). The UNIDO report further elaborates “that manufacturing challenges and opportunities are driven by increasingly complex and globalised nature of industrial systems, the dramatic reduction in manufacturing timescales and the acceleration of technological developments and innovation” (UNIDO,2016:v).

2.2. THE GLOBAL FERTILISER MARKET

To be able to understand the international fertiliser market, one must appreciate the international energy market. Historically, crude oil prices have been on a steady upward trend post the global financial crisis of 2008 until late 2014. This may be seen from figure 2.1 below. The sharp decline in the crude oil price at the end of 2014 resulted in a significant global shift away from natural gas, as a source of energy, towards crude oil.

Figure 2.1: Crude oil price trend from 2007 to 2017



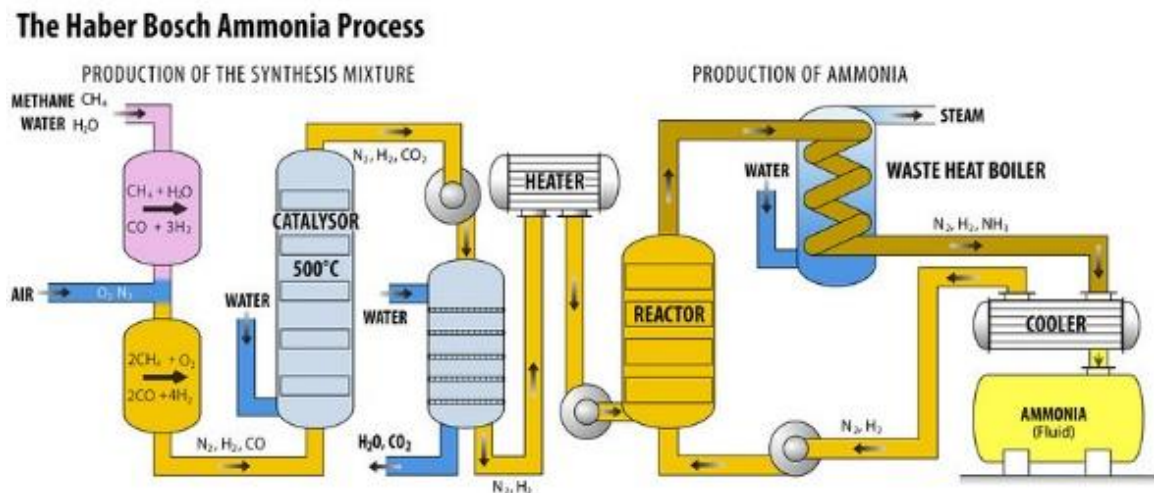
Source: Index Mundi

The decline in the crude oil price was as a result of the increased production of oil from oil producing nations, in an attempt to defend their market position against newly constructed natural gas field operations. The resulting crude oil price drop rendered numerous natural gas supply projects unprofitable with much excess capacity in natural gas available.

As the demand for natural gas fell, the price of natural gas then decreased significantly. This decrease in the price of natural gas sparked an increase in major

investment of fertiliser manufacturing facilities, as natural gas is a critical feedstock for the production of ammonia, which is itself a key raw material for the chemical fertiliser market. The process which converts natural gas, or methane, to ammonia is shown in figure 2.2 below.

Figure 2.2: The Haber Bosch ammonia process



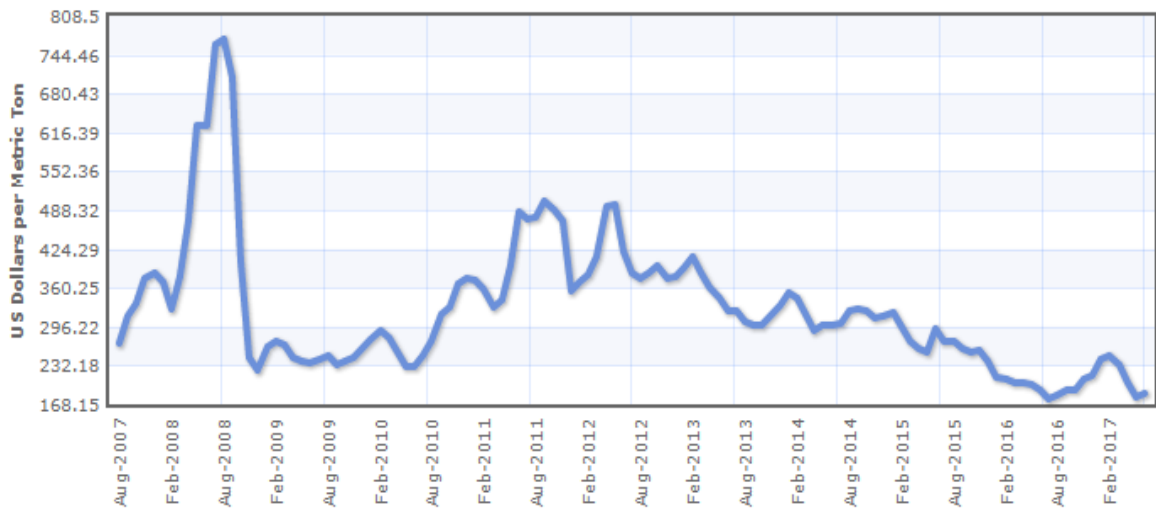
Source: Smug Mug

In addition, as a further consequence to the natural gas supply glut and low prices, traditional oil rich producing nations of the Middle East then strategically began to diversify themselves away from the oil and petrochemical industries.

In Saudi Arabia for example, the Ma'aden project was strategically pursued to become a major industrial sector after oil and petrochemicals (Ma'aden:2016). This major investment, has contributed to the supply glut of chemical fertiliser across the global market as the facility begun production.

Chemical fertiliser is seen as a commodity and as such, its price is determined by the international market. A global supply glut translates into increased competition for market sales as well as an overall reduced selling price per unit of product. The effect of this supply glut on fertiliser prices may be seen in figure 2.3 below.

Figure 2.3: Urea (chemical fertiliser) price trend from 2007 to 2017



Source: Index Mundi

In order for local chemical fertiliser manufacturers to compete with multinational chemical fertiliser producing giants during a supply glut, they must reduce their cost per unit by improving productivity within their processes.

2.3. INNOVATION, THE KEY TO SUSTAINABLE COMPETITIVENESS

Ahuja *et al.* (2007:338) confirm that “the global competition characterized by the rapid technological innovations and ever-changing market demands is putting enormous pressure on manufacturing organisations across the globe.” The current economic climate has led many organisations to turn to innovation as a competitive edge.

Innovation has been described as fundamental to a manufacturing firm’s profitability and sustainability (Pan & Li, 2016:136). Furthermore, Terziovski and Sohal (2000:539) elaborate on this by stating that “long term competitiveness is

increasingly dependent on how well a company can continuously improve its product development capabilities by fostering organisational learning and utilising individual and group knowledge within the company.” The continuous improvement concept has been described as a great instrument to attain such competitive advantages (Garcia-Sabater *et al.*, 2012:99).

Flynn and Flynn (1996:360) further contribute to the above research by stating that “by achieving continuous improvement through-out the firm, world class manufacturers can provide products that achieve economies of scope (cost reduction through the ability to share activities), as well as revised economies of scale (cost reduction through the efficiencies associated with high volume production) which result in products that can attain and sustain several competitive advantages simultaneously.” Additionally, Flynn and Flynn (1996:364) deduce that the continuous improvement of a manufacturing capability is directly related to improving its competitive position.

Singh and Singh (2013:33) describe continuous improvement as an overarching umbrella of multiple roll-out strategies namely; Total Productive Maintenance (TPM), Six Sigma, Just-In Time (JIT), Total Quality Management (TQM), Failure Mode Effect Analysis (FMEA), and 5S. The actual deployment and selection of these concepts are often at the discretion of management to implement.

Seng *et al.* (2007:53) explored further on how TPM assists manufacturing firms by stating that “many organisations have implemented TPM to improve their equipment efficiency and to obtain the competitive advantage in the global market in terms of cost and quality.”

Previous research conducted in the Australian manufacturing environment suggests that the majority of organisations introduced the continuous improvement concepts to only part of their operations (Terziovski & Sohal,

2000:550). Additionally, Terziovski and Sohal (2000:550) found organisational performance, in the Australian manufacturing environment, to be dependent on the maturity and the extent of deployment of the continuous improvement program within the organisation.

2.4. FOCUSED IMPROVEMENT

Focused improvement is one of the eight core fundamentals of the TPM program. The others being autonomous maintenance, planned maintenance, training and education, early equipment management, quality maintenance, TPM in administration, as well as safety and environmental management.

The major difference between focused improvement and other continuous improvement programmes, is that focused improvement is aimed at multi-disciplinary teams generating ideas and solutions to improve the overall process. As opposed to the fabrication and assembly industries, which focusses solely on equipment related losses, focused improvement is aimed at any object which affects the overall system including a sub process, a material flow system, a piece of machinery, or a procedure.

Focused improvement is defined by Suzuki (1994:45) as “all activities that maximise the overall effectiveness of equipment, processes, and plants through uncompromising elimination of losses and improvement of performance”. Seng *et al.* (2007:53) further contribute to this by stating that “efficiency and effectiveness of equipment plays a dominant role in modern manufacturing industry to determine the performance of the organizational production function as well as the level of success achieved in the organization”.

According to Ahuja *et al.* (2007:341) “TPM employs overall equipment effectiveness (OPE) as a quantitative metric for measuring the performance of a productive system.” Suzuki (1994:30) define OPE as “the product of availability, performance rate and quality rate”. This is:

$$OPE = Availability (A) \times Performance Rate \times Quality Rate$$

where:

$$Availability (A) = \frac{Calendar Time - (shutdown loss + major stoppage loss)}{Calendar Time} \times 100\%$$

$$Performance Rate = \frac{average actual production rate}{standard production rate} \times 100\%$$

and

$$Quality Rate = \frac{Produced quantity - (quality defect loss + reprocessing loss)}{produced quantity} \times 100\%$$

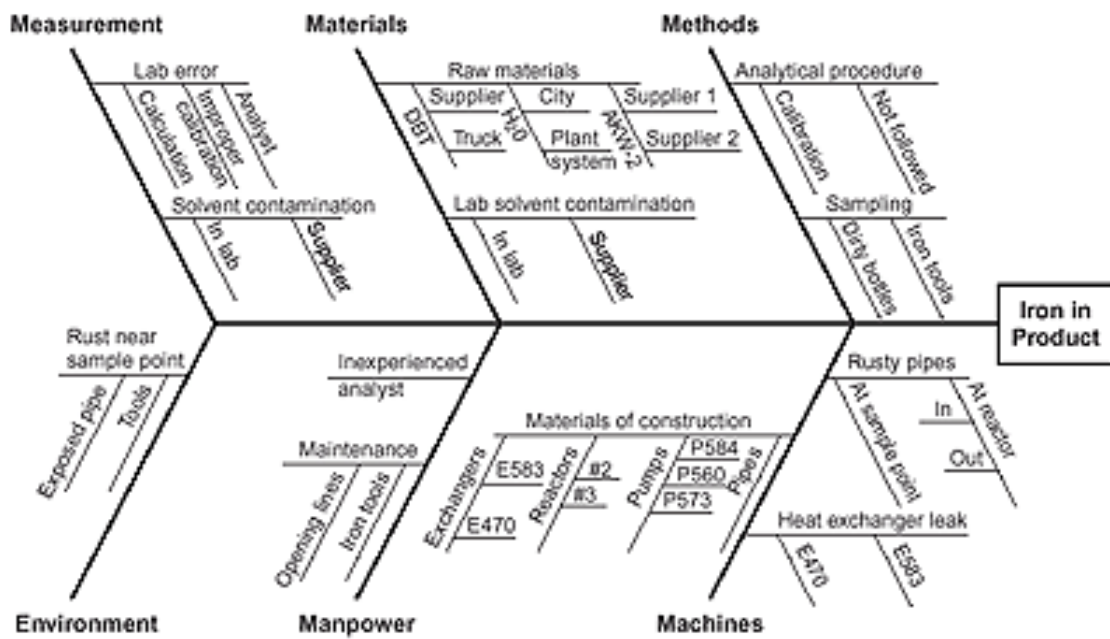
Availability refers to the nett online time available for production to occur, while the performance rate is a measure of the actual rate of production achieved against the standard design rate for that specific manufacturing plant. The quality rate is a measure of nett production of on-specification product against the total product manufactured. The product of availability, performance rate and the quality rate is referred to as the OPE. By implication, the maximisation of OPE means the maximisation of the availability, performance rate and the quality rate.

Focused improvement is based on the Theory of Constraints, which states “that at any given point of time, the system has only one restriction” (Demchuck *et al.*, 2014:23). Demchuck *et al.* (2014:23) further elaborate that “bottlenecks can be any portion of the company – workshop, warehouse, machine or even a particular person.”

Focused improvement comprises of a periodic loss analysis, which highlights the major bottlenecks or losses of the manufacturing plant to the multi-disciplinary team. The team then focuses its efforts on a solution to relieve the bottleneck and increase the OPE through a project or change in the system.

Typical tools used in the decision making process and root-cause analysis are the Pareto charts, 5 Why tables and Ishikawa or fishbone diagrams. An example of an Ishikawa or fishbone diagram may be seen in figure 2.4 below.

Figure 2.4: A typical example of the Ishikawa or fishbone diagram used in the steel industry



Source: American Society for Quality

2.5. THE EIGHT STEP APPROACH TO FOCUSED IMPROVEMENT

Suzuki (1999:53) describes the eight activity steps to focused improvement as follows:

STEP 1 (Select improvement topic):

Improvement topics are selected and registered by the lead engineer. This is performed to ensure alignment between the selected topic and the company's strategy. During this step, a project team is additionally formed to address the problem.

STEP 2 (Understand the situation):

The project team then identifies bottlenecks within the process based on the loss analysis. The identified bottleneck's failure rates and defects analysis are used to establish a baseline, from which a target is set for improvement.

STEP 3 (Expose and eliminate abnormalities):

The abnormal conditions of the bottleneck are thoroughly investigated. The improvement team then attempts to restore basic equipment conditions and prevents further deterioration.

STEP 4 (Analyse Causes):

The losses causing the failure are then examined using technical tools such as the failure mode effect analysis (FMEA).

STEP 5 (Plan improvement):

The improvement team then drafts proposals to rectify the root cause of the problem. All possible proposals are then evaluated for cost-effectiveness. A project budget is then compiled on the selected improvement proposal for approval. A hazard analysis is also conducted at this stage to mitigate against any potential risks identified post implementation.

STEP 6 (Implement improvement):

The improvement plan is then executed. Any changes to operating or maintenance procedures are then updated and submitted to the training department for re-training.

STEP 7 (Analyse results):

The results of the project are evaluated over time. The project results are compared with the initial estimated targets to verify if the actual intervention yielded any improvement at all. If the desired target is not met, the team then moves back to STEP 4 above.

STEP 8 (Consolidate gains):

Standard controls (such as manuals and work standards) are then drawn up to sustain the results achieved. The controls are then fed back to operational and maintenance teams.

2.6. THE EIGHT MAJOR MANUFACTURING PLANT LOSSES

The eight major plant losses, affecting availability, performance rate and the quality rate (and by implication the OPE), defined by the focused improvement pillar of TPM, are: shutdown losses, production adjustments, equipment failures, process failures, normal production loss, abnormal production loss, quality defects and reprocessing losses (Suzuki,1999:23).

Shutdown losses refer to the time lost due to periodic maintenance activities required throughout the year. These activities are essential to restore equipment conditions and for maintaining plant performance.

Production adjustments are those losses incurred when the manufacturing plant is subjected to changes in the demand and supply of the manufactured product and time is lost due to this change within the production plan.

Equipment failures refers to the time lost when the manufacturing plants stops due to sudden loss of an equipment function. This is commonly referred to as an equipment breakdown.

Process failure losses refer to the loss incurred when a manufacturing plant stops due to a change in the raw material physical or chemical quality, or an operator error or misjudgement.

Normal production losses are those losses that are recorded when a manufacturing plant produces at a reduced rate, due to plant start up, shutdown and or changeover of products.

Abnormal production losses are those losses that are recorded when the plant produces at a production rate that is less than the standard production rate due to equipment malfunction. Abnormal losses affect the performance rate of the plant.

Quality defect losses refers to the time lost while producing poor quality product which is off specification and cannot be sold to the market. Quality defect losses affect the quality rate of the plant.

Reprocessing losses are those losses incurred when off specification product or poor quality product must be reworked through the manufacturing plant. Reprocessing losses additionally affect the quality rate of the plant.

CHAPTER 3

RESULTS AND DISCUSSION OF THE STUDY

3.1. INTRODUCTION

The primary purpose of this chapter is to present, discuss and interpret the results obtained from the study performed. The study attempts to determine the impact of implementing continuous improvement on manufacturing performance, within a fertiliser company.

However, prior to presenting, discussing and interpreting the results obtained, the chapter will additionally discuss the specific case of the quasi-experimental study undertaken and the challenges experienced in the data analysis of these studies.

3.2. THE QUASI-EXPERIMENTAL STUDY

As mentioned in chapter 1, the experimental study conducted was achieved by observing two manufacturing departments, within a fertiliser producing company, in their naturally occurring states.

According to Bryman *et al.* (2015:101), a classical experimental study occurs when “the researcher creates two groups and this division into two groups forms the basis for experimental manipulation of the independent variable.” In this case, the researcher assigns the groups at random to ensure that any difference between them, is solely attributable to the influence of the independent variable. The group which received the treatment or influence, is usually referred to as the

experimental group or intervention group and the other group, which did not receive any treatment, is referred to as the control group.

Alternatively, an experimental study may also exist when the groups being studied occur in their natural states, as in the study undertaken. This type of experimental study is referred to as a quasi-experimental study. Quasi-experimental studies normally occur when it is not feasible or practical for the researcher to assign the groups to treat or influence at random. In the case of the study undertaken, the manufacturing departments that applied continuous improvement were not randomly assigned. Therefore the study undertaken would be classified as a quasi-experimental study.

3.3. STATISTICAL ANALYSIS OF QUASI-EXPERIMENTAL STUDIES

According to Campbell and Boruch (cited by Olejnik, 1978:2), quasi-experimental studies are difficult to analyse and interpret due to the issue of estimating the bias in treatment or intervention effects. Olejnik (1978:2) further elaborates that “the entire problem originates from the fact that without randomization there are likely to be substantial differences between the individuals in their initial status on the outcomes to be assessed.”

With respect to the study undertaken, these pre-test differences may be due to any one of the following reasons:

- the maturity and professional experience of the continuous improvement team members at each of the manufacturing departments
- the structural composition and combination of the continuous improvement teams at each of the manufacturing departments
- the bias of management to pursue capital investment projects at each of the manufacturing departments during the pre-test phase

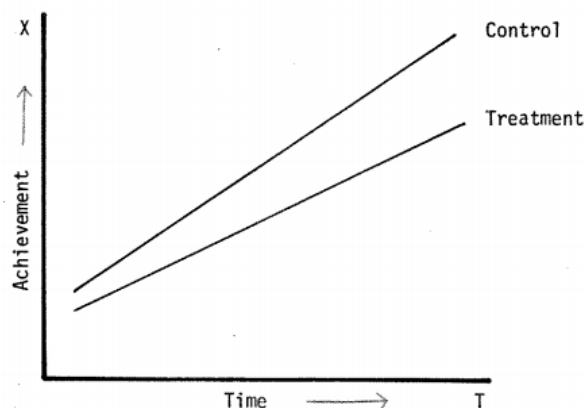
Therefore, it is imperative to the results of this study, to be able to understand the naturally occurring growth or improvement rates in OPE of each department prior to the intervention of implementing continuous improvement. These differences should then be taken into account when actually evaluating the true effect of the intervention or treatment.

The following subsection 3.4 describes the literature reviewed, in order to find a suitable model to be used to determine the true effect of the intervention within a quasi-experimental study described above.

3.4. THE FAN SPREAD HYPOTHESIS

Olejnik (1978:1) discussed and dealt with the data analysis strategies used in quasi-experimental studies. Olejnik (1978:2) describes the fan spread hypothesis which is primarily concerned with the relationship between growth rates and estimates of treatment effects. The hypothesis states that the initial differences on the outcome dimension imply differential growth rates. This may be seen in figure 3.1 below:

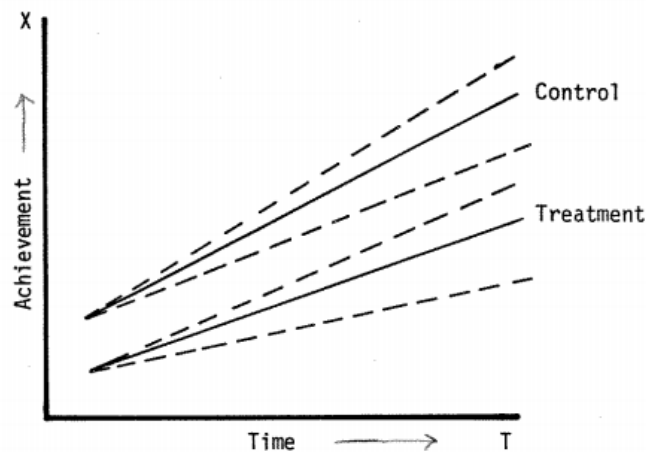
Figure 3.1: The selection by maturation interaction: increasing mean differences in achievement between comparison groups across time



Source: (Olejnik, 1978: 3)

Olejnik further discusses the hypothesis and states that “along with the increasing mean difference between the compared groups, a proportional increase in the variance within the groups occurs” (Olejnik, 1978:3). The above figure 3.1 is then modified to incorporate the changing variance. This is shown in figure 3.2 below. The dashed or broken line in figure 3.2, represents the increasing range of achievement within both the treatment and control groups over time.

Figure 3.2: The fan spread hypothesis: increasing mean difference in achievement between comparison groups with a proportional increase in the within-group variability across time

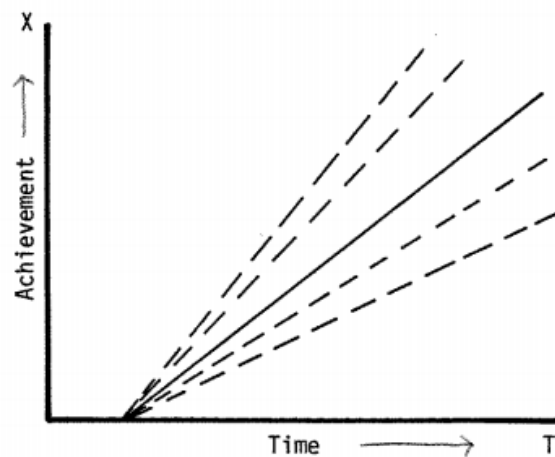


Source: Olejnik (1978: 4)

However, the discussion up to this point has ignored the differential growth rates within groups and primarily focused on differential growth rates between groups. Olejnik (1978:5) conceptualises this further in the below figures 3.3 and 3.4.

The solid line in figure 3.3 above, represents the average growth rate of the group and the dashed lines the individual growth rates within the group. The growth rates within the group begin at the same start point, while individual growth rates vary with time. According to Olejnik (1978:7), “thus in any two subsequent points in time, individuals maintain their relative positions within the group.”

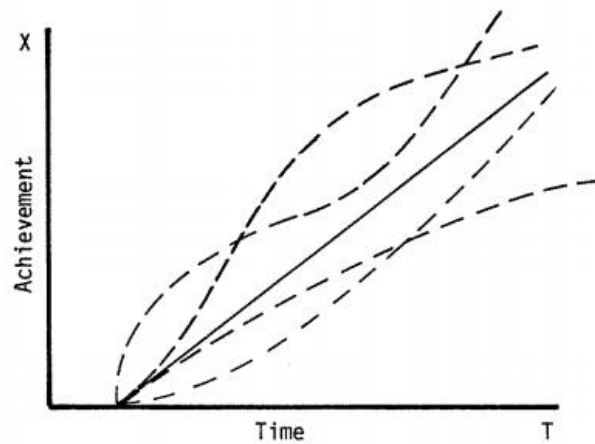
Figure 3.3: The fan spread hypothesis with the linear model of within group growth



Source: Olejnik (1978: 5)

However, in the below figure 3.4, the group’s mean growth is linear but the individual growth rate is not. In other words, in this model, the individual’s growth rate may vary over time as there may be periods of growth spurts and growth rate decline. The solid line in figure 3.4 below, represents the case where the groups mean improvement is linear but the individual growth rate is not.

Figure 3.4: The fan spread hypothesis with a non-linear model of within group growth



Source: Olejnik (1978: 6)

With regard to the Fan Spread Hypothesis, Olejnik further goes onto to test each of the following data analytical strategies namely (1978:15):

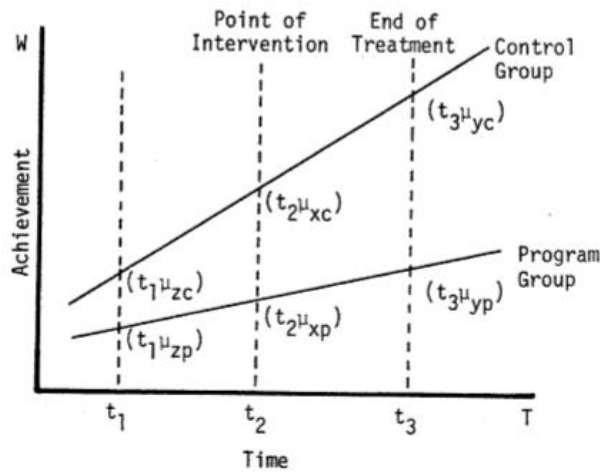
- The gains in standard scores strategy
- The single co-variable analysis of covariance with estimated true scores
- The gain scores adjusted for differential growth rates
- The multiple fallible co-variable analysis of covariance

Olejnik tests for accuracy and precision in each of the abovementioned analytical strategies and eventually found that “the most desirable analytical strategy of those considered is the gain scores adjusted for differential growth rates” (1978:36).

3.5. THE ADJUSTED GAIN SCORES MODEL FOR DIFFERENTIAL GROWTH RATES

In his analysis of the adjusted gain score for differential rates procedure, Olejnik (1978:13) depicts the typical quasi-experimental study under consideration in figure 3.5 below.

Figure 3.5: Differential growth rates over three points in time



Source: Olejnik (1978: 10)

In figure 3.5 above, t_1 represents some time prior to the intervention, t_2 the point of intervention and t_3 the point at the termination of the intervention. Therefore the period of intervention is represented by $t_3 - t_2$. The symbol μ represents the population mean for each group and the subscript c and p denotes the control and program groups respectively. The additional subscript z , x and c , further denote the population mean at t_1 , t_2 and t_3 respectively.

After rigorous derivation, Olejnik (1978:13) defines the following model to account for “the difference in average performance of the program and control groups at the termination of the intervention”:

$$\alpha_{AGS} = \mu_{YP} - \mu_{YC} - \left[\frac{(\mu_{xp} - \mu_{zp}) - (\mu_{xc} - \mu_{zc})}{(t_2 - t_1)} (t_3 - t_2) \right]$$

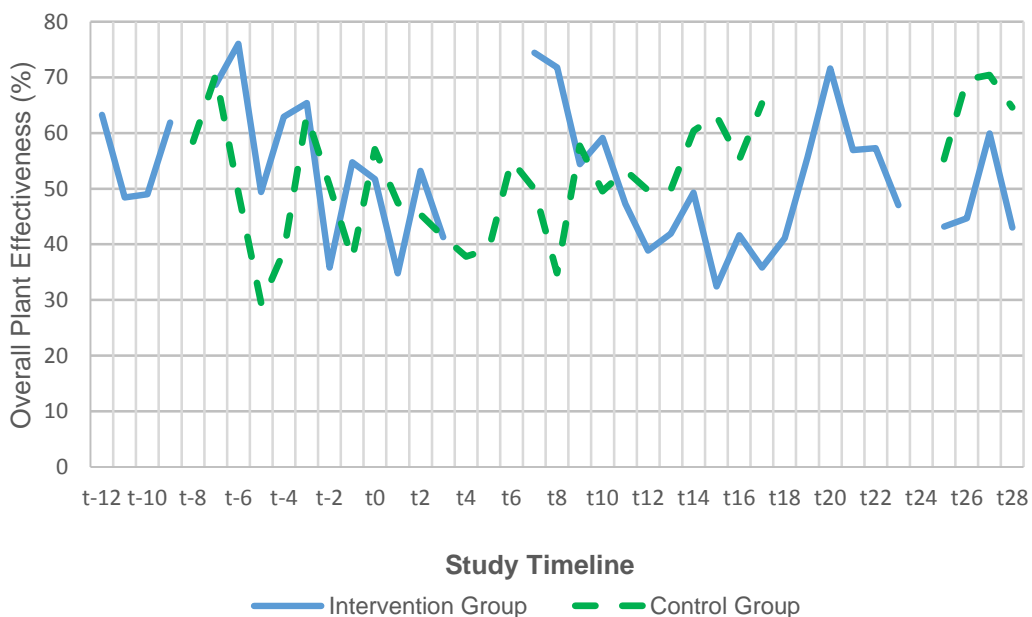
Source: Olejnik (1978: 13)

The above model, in its assessment of the impact of the intervention, additionally takes the differential growth rates of each group prior to the intervention into account.

3.6. RESULTS OF THE DATA GATHERED

The raw availability, quality and performance rates were collected for both manufacturing departments. This, together with the resultant calculated OPE for both the control and intervention groups, may be seen in Table A in Appendix A. A graphical depiction of OPE for the intervention and control groups may be seen in figure 3.6 below.

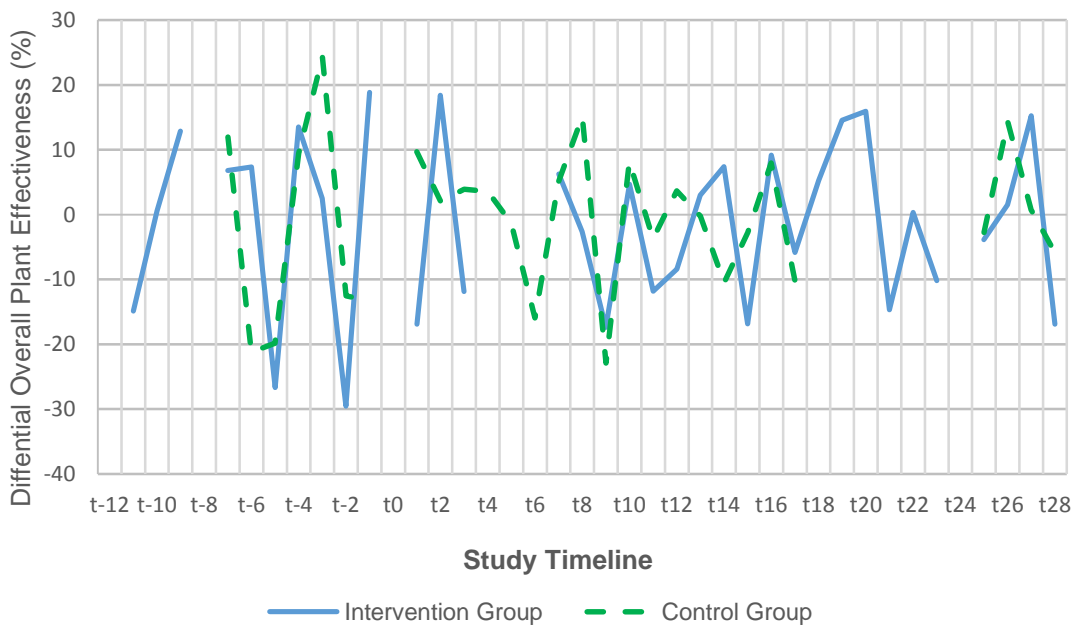
Figure 3.6: Raw OPE for intervention and control groups



For the study conducted, the intervention occurred from time t_0 to time t_{23} . Data points from t_{-12} to t_0 represent the period prior to intervention, while data points from t_{23} to t_{28} represent the period post intervention.

The raw OPE data was then manipulated to calculate the differential OPE per data point. The calculated differential OPE may be seen in Table B in Appendix B. For the study conducted, the differential OPE would represent the month to month change, or incremental improvement in OPE of the department under consideration. A graphical depiction of the differential OPE for the intervention and control may be seen in figure 3.7 below.

Figure 3.7: Differential OPE for intervention and control groups



By applying the adjusted gain scores for differential growth rates model to the differential OPE data, the following results are observed in table 3.1 below.

Table 3.1: Results for the adjusted gain score model

	Intervention Group (%)	Control Group (%)
μ_z	-0,86	-3,02
μ_x	0,28	-0,48
μ_y	-0,04	-0,14
α_{AGS}	2,90	

From the results depicted in table 3.1, it may be seen the mean differential OPE of the intervention and control group, prior to the intervention, is -0.86% and -3.02% respectively. This historical performance suggests that both groups' OPE were deteriorating, with the control group being the worse of the two.

During the intervention, it could be noted that the intervention group showed a positive mean differential OPE of 0.28%, as compared with the control group's performance -0.48% during the same period. This result is in line with the expectation as the implementation of continuous improvement is intended to improve and maximise OEE.

It should also be noted, that during the period of the intervention, the control group improved its performance naturally from -3.02% to -0.48% in their mean differential OPE. This improvement may be solely attributed to the natural development of the work teams, and is additionally in line with expectations as one would expect the group's performance to naturally improve with time. That being said, the control group did not manage to post a positive improvement in differential OEE as its overall performance continued to deteriorate during the 24 month period of intervention.

By applying the adjusted gain scores for differential growth rates model, a positive α_{AGS} of 2.90% is achieved. In other words, the model resulted in a positive difference with respect to differential OPE for the intervention and control groups. The resulting difference is in favour of the intervention group and by implication, the implementation of continuous improvement.

Another notable point from the results may be seen post intervention, as the intervention group's performance in their mean differential OPE deteriorated from 0.28% to -0.14%. Once again, this result confirmed the expectation that the removal of the continuous improvement program from the intervention group was then detrimental to their overall performance of the group. Furthermore, it is also noted that the control group continued to improve their performance in their mean differential OPE during this period from -0.48% to -0.14%.

At the end of the study, it may also be noted that both the intervention and control groups' performance in mean differential OPE was almost the same post intervention. Both groups registered a negative deterioration in performance of their mean differential OPE during the post intervention period.

3.7. MEASUREMENT VALIDITY AND RELIABILITY

According to Bryman *et al.* (2015:25), measurement validity is a criterion which “applies to quantitative research and to the search for measures of social scientific concepts.” It is also referred to as construct validity, and seeks to understand whether or not the chosen measure of the construct really reflects the concept studied. Bryman *et al.* (2015:25) elaborate on this further by reflecting on measurement validity by asking “does the measure really represent the concept it is supposed to be tapping?”

Additionally, measurement validity is closely related to reliability. If the selected measure of a construct is “unstable and hence unreliable, it cannot be providing a valid measure of the concept” (Bryman *et al.*, 2015:26).

In order to confirm the internal reliability of the raw data, Cronbach’s alpha was calculated. “Cronbach’s alpha is a measure of internal consistency, that is, how closely related a set of items are as a group. (Institute for Digital Research and Education, 2017). Cronbach’s alpha varies from 0 to 1, with values greater than or close to 0.7 usually being accepted as an appropriate indication internal consistency.

With respect to the study undertaken, Cronbach’s alpha was calculated to be 0.67 for both the control and intervention group’s raw data sets. Since the value is close to 0.7, the data was included in this study.

3.8. ANALYSIS AND INTERPRETATION OF THE RESULTS

The results displayed suggest that the structured strategic approach to improvement and innovation, which is the implementation of continuous improvement, positively influences OPE. The suggestion is due to:

- the improvement of the intervention group's performance from a negative mean differential OPE of -0.86% to a positive mean differential OPE of 0.28% during the intervention.
- the deterioration of the intervention group's performance from a positive mean differential OPE of 0.28% to a negative mean differential OPE of -0.14% post intervention.
- when comparing both groups performance over the entire study, the only positive differential OPE observed occurred during the intervention. The control group did not record any positive mean differential OPE.
- the intervention group's performance in mean differential OPE consistently outperformed the control group's performance in mean differential OPE throughout the study.
- the model presented by Olejnik (1978:13) confirming a positive difference of 2.90% in the mean differential OPE in favour of the intervention group.

The abovementioned result was to be expected as the intervention group approached their losses in a structured strategic manner. The group concentrated on the identified major losses as a priority, before tackling any other issues on the production line. This methodology is in line with the Theory of Constraints as discussed in Chapter 2.

The results additionally suggest that the subjective approach to improvement and innovation practiced by the control group does not positively influence OPE. The suggestion is due to:

- the control group's performance recording negative mean differential OPE throughout the three phases of the study.

If the two approaches undertaken by both groups are compared, the results suggest that the structured strategic approach of implementing continuous improvement is better than the subjective approach due to:

- the control group's performance in the mean differential OPE consistently underperforming the intervention group's performance in the mean differential OPE throughout the study.
- the model presented by Olejnik (1978:13) confirming a positive difference of 2.90% in the mean differential OPE in favour of the intervention group.

3.9. PRACTICAL SIGNIFICANCE OF THE RESULT

The result of an increase of approximately 2.90% in mean differential OPE must be considered practically, due to the nature of the construct used. The ordinary man that reads this result, may not necessarily consider this improvement to be noteworthy, however, if it is further translated into economic savings, it will be appreciated accordingly.

The increase of 2.90% in mean differential OPE, within the context of the fertiliser company in question, resulted in an increase of approximately 6.03% in additional product produced within the same facility. This additional product produced at the same cost, translates into an improved economies of scale for the company as the final product cost of fertiliser was subsequently reduced by 5.69% accordingly. In terms of the business, these cost savings are directly posted in the income statement and provide a greater gross profit margin to the company concerned.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1. INTRODUCTION

The purpose of this chapter, on assessing the influence of continuous improvement on manufacturing performance, is to conclude on the quasi-experimental study discussed in Chapter 3. This chapter will revisit the objectives of the study and describe recommendations to the organisation in terms of its strategic approach to implementing innovation and improvement. The chapter will additionally suggest areas for future research.

4.2. CONCLUSIONS

The following conclusions drawn are based on the quasi-experimental study discussed in Chapter 3. These are:

4.2.1. Continuous improvement influences manufacturing performance positively

From the results obtained, it was clearly evident that the intervention group, that practiced continuous improvement during the study, improved their differential OPE, and by implication their manufacturing performance positively. Their differential OPE improved from -0.86% prior to the intervention, to +0.28% during the intervention.

It is additionally noted that this department's manufacturing performance was actually deteriorating prior and post intervention, as its month to month incremental OPE was on average negative during these periods. Such a dramatic change in long term performance, may well be attributable to the practices of the department as their focus to improve and implement innovation reverted to subjective opinions and managerial influence.

4.2.2. The lack of continuous improvement influences manufacturing performance negatively

By contrast, the control group, that did not practice continuous improvement during the study, gradually improved their differential OPE throughout the 3 phases of the study. This gradual, slow improvement, could be attributed to the natural development and gain in experience of the department and work teams.

Critically however, the control group, did not manage to record a positive differential OPE, but instead their differential OPE remained negative throughout the study. This performance would indicate that the subjective approach to implementing improvement and innovation, driven by opinion strength and managerial influence, did not allow the department to positively improve their manufacturing performance at all.

4.2.3. The structured approach of continuous improvement outperformed the subjective approach to innovation and improvement

By comparison, the adjusted gains scores for differential growth rates model, developed by Olejnik (1978:13), presented a positive difference of 2.90% in differential OPE between the intervention and control group's overall performance, in favour of the intervention group. This positive difference took the initial performance differences of both groups into account, as well as the within group variation. The result of the model confirms that intervention group outperformed the control group during the study. This may well be attributed to

the implementation of continuous improvement at the intervention group, as all forms of innovation and improvement, in this group, strictly followed the continuous improvement philosophy described in Chapter 2.

4.3. A CRITICAL EVALUATION OF PRIMARY OBJECTIVES

This section critically evaluates the successful adherence to the primary objectives described in section 1.3.1.

The primary objective of this study were to:

- I. analyse the objective approach to improvement and innovation, which is the effect of continuous improvement on manufacturing performance within a South African fertiliser company
- II. analyse the traditional subjective approach to improvement and innovation on manufacturing performance within a South African fertiliser company
- III. compare the objective approach and subjective approach and make a suitable recommendation to the organisation in terms of their improvement strategy

The first primary objective was achieved as the effect of the objective approach to improvement and innovation, which is the effect of continuous improvement on manufacturing performance was analysed. The results, as described in section 4.2.1., was positive.

The second primary objective was achieved as the effect of the traditional subjective approach to improvement and innovation on manufacturing performance was analysed. The results, as described in section 4.2.2., was negative.

The third primary objective was achieved as the objective and subjective approaches were analysed and compared. The result is in favour of the objective approach to innovation and improvement. The recommendation to the organisation is discussed in section 4.4 below.

4.4. RECOMMENDATIONS TO THE ORGANISATION

As concluded in section 4.2 above, the implementation of continuous improvement at the manufacturing department had clearly benefitted the department in terms of its manufacturing performance. Apart from this improvement, other benefits were noted during the study conducted:

- the structured approach to problem solving increased the team's effectiveness as the work group was forced to analyse the problems at the manufacturing plant from an objective view, due to the use of the 5 Why and fishbone tools.
- the department's managerial influence was subdued during the intervention. The positive result of this study could potentially lead the manager to develop a positive opinion of continuous improvement. This change in attitude may play a pivotal role in assisting the organisation with the change management that must occur in other departments, once the methodology is rolled out. Furthermore, even if continuous improvement were ceased at the organisation, the manager of the intervention group may well decide to prioritise continuous improvement practices, when determining the improvement focus of the department.
- the communication of the highest losses of the manufacturing department through visual management tools such as Pareto charts, resulted in a greater engagement of the shop floor employees in understanding and attempting to assist in dealing with the problems facing the manufacturing performance.

It is therefore recommended to the organisation that it continue the deployment of continuous improvement throughout its manufacturing operations in an attempt to reap the benefits in manufacturing performance as well as the abovementioned benefits.

4.5. RECOMMENDATIONS FOR FUTURE RESEARCH

As described in chapter one, the ultimate purpose for implementing continuous improvement within a manufacturing facility is the intended benefit of cost reduction of the final product. As this cost reduction is achieved through the increased productivity and efficiency at the plant, a suitable multifactor measurement of product cost must be used to support future research findings.

The multifactor measurement must incorporate various cost areas such as:

- energy consumption
- labour utilisation
- raw material inputs
- routine machine maintenance costs
- capital investment projects
- utility consumption

For future studies in this area, it is therefore recommended that the total operational cost per metric tonne produced be incorporated into the study as a suitable multifactor measurement. The total cost per metric tonne produced incorporates all the above mentioned cost areas and will provide additional support to confirm the success of the implementation of the continuous improvement methodology.

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APPENDIX A

Table A: Raw availability, quality and performance rate data for intervention and control groups

Time	Intervention status	Control Group				Intervention Group			
		Performance Rate	Quality Rate	Availability Rate	OPE	Availability Rate	Performance Rate	Quality Rate	OPE
t-12	Prior to intervention	n/a	n/a	n/a	n/a	61,00	105,42	98,41	63,28
t-11	Prior to intervention	n/a	n/a	n/a	n/a	57,00	91,83	92,50	48,42
t-10	Prior to intervention	n/a	n/a	n/a	n/a	60,00	81,67	100,00	49,00
t-9	Prior to intervention	n/a	n/a	n/a	n/a	76,00	82,75	98,36	61,86
t-8	Prior to intervention	75,41	96,36	80,42	58,44	n/a	n/a	n/a	n/a
t-7	Prior to intervention	71,93	97,80	100,10	70,42	78,00	91,25	96,49	68,68
t-6	Prior to intervention	64,43	97,53	78,25	49,17	80,00	98,50	96,50	76,04
t-5	Prior to intervention	53,89	98,65	55,17	29,33	55,00	104,75	85,71	49,38
t-4	Prior to intervention	48,15	99,54	80,91	38,79	76,00	96,33	85,94	62,92
t-3	Prior to intervention	65,76	99,26	96,77	63,17	75,00	93,67	93,10	65,40
t-2	Prior to intervention	69,62	99,04	73,44	50,64	64,00	96,75	57,89	35,85
t-1	Prior to intervention	64,35	98,19	59,07	37,32	64,00	98,08	87,18	54,73
t0	Intervention	75,60	97,93	77,12	57,10	78,00	84,17	78,72	51,68
t1	Intervention	72,23	99,27	66,12	47,41	78,00	78,00	57,14	34,76
t2	Intervention	66,34	97,92	69,76	45,32	76,00	98,33	71,15	53,17
t3	Intervention	61,58	99,79	67,36	41,39	73,00	102,25	55,31	41,28
t4	Intervention	76,85	100,00	49,22	37,82	n/a	n/a	n/a	n/a
t5	Intervention	67,63	98,84	58,52	39,12	77,00	96,58	91,67	68,17
t6	Intervention	69,34	99,15	80,11	55,08	n/a	n/a	n/a	n/a
t7	Intervention	59,82	97,81	85,37	49,95	76,00	97,92	100,00	74,42
t8	Intervention	73,33	100,00	47,46	34,80	79,00	96,25	94,44	71,81
t9	Intervention	75,19	100,00	76,77	57,72	64,00	93,67	90,77	54,41
t10	Intervention	79,51	99,05	62,90	49,54	79,00	91,83	81,48	59,11
t11	Intervention	76,22	98,95	70,66	53,29	61,00	92,58	83,72	47,28
t12	Intervention	74,07	99,63	67,27	49,64	64,00	89,33	68,00	38,88
t13	Intervention	75,28	99,43	66,63	49,87	59,00	89,42	79,41	41,89
t14	Intervention	76,24	99,76	79,41	60,40	39,00	92,25	51,85	18,65
t15	Intervention	74,66	98,83	85,58	63,15	69,00	91,58	78,00	49,29
t16	Intervention	74,16	98,60	75,49	55,20	61,00	94,58	56,25	32,45
t17	Intervention	76,48	99,85	85,50	65,30	57,00	105,25	69,39	41,63
t18	Intervention	n/a	n/a	n/a	n/a	60,00	103,42	57,69	35,80
t19	Intervention	n/a	n/a	n/a	n/a	59,00	97,50	71,43	41,09
t20	Intervention	n/a	n/a	n/a	n/a	66,00	96,33	87,50	55,63
t21	Intervention	n/a	n/a	n/a	n/a	72,00	108,08	92,00	71,59
t22	Intervention	n/a	n/a	n/a	n/a	61,00	100,33	93,00	56,92
t23	Intervention	66,57	99,85	87,37	58,07	58,00	100,75	98,00	57,27
t24	Post intervention	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
t25	Post intervention	77,13	93,52	76,69	55,32	61,00	52,42	93,94	30,04
t26	Post intervention	77,21	99,77	90,39	69,63	59,00	93,17	78,57	43,19
t27	Post intervention	80,20	98,40	89,22	70,41	61,00	104,67	70,00	44,69
t28	Post intervention	82,52	98,58	79,43	64,61	56,00	113,33	94,44	59,94

APPENDIX B

Table B: Calculated differential OPE data for intervention and control groups

Time	Intervention status	Control Group		Intervention Group	
		OPE (%)	Differential OPE (%)	OPE (%)	Differential OPE (%)
t-12	Prior to intervention	n/a	n/a	63,3	n/a
t-11	Prior to intervention	n/a	n/a	48,4	-14,9
t-10	Prior to intervention	n/a	n/a	49,0	0,6
t-9	Prior to intervention	n/a	n/a	61,9	12,9
t-8	Prior to intervention	58,4	n/a	n/a	n/a
t-7	Prior to intervention	70,4	12,0	68,7	6,8
t-6	Prior to intervention	49,2	-21,2	76,0	7,4
t-5	Prior to intervention	29,3	-19,8	49,4	-26,7
t-4	Prior to intervention	38,8	9,5	62,9	13,5
t-3	Prior to intervention	63,2	24,4	65,4	2,5
t-2	Prior to intervention	50,6	-12,5	35,8	-29,6
t-1	Prior to intervention	37,3	-13,3	54,7	18,9
t0	Intervention	57,1	0,0	51,7	0,0
t1	Intervention	47,4	9,7	34,8	-16,9
t2	Intervention	45,3	2,1	53,2	18,4
t3	Intervention	41,4	3,9	41,3	-11,9
t4	Intervention	37,8	3,6	26,9	-14,3
t5	Intervention	39,1	-1,3	68,2	41,2
t6	Intervention	55,1	-16,0	n/a	0,0
t7	Intervention	50,0	5,1	74,4	6,2
t8	Intervention	34,8	15,1	71,8	-2,6
t9	Intervention	57,7	-22,9	54,4	-17,4
t10	Intervention	49,5	8,2	59,1	4,7
t11	Intervention	53,3	-3,8	47,3	-11,8
t12	Intervention	49,6	3,7	38,9	-8,4
t13	Intervention	49,9	-0,2	41,9	3,0
t14	Intervention	60,4	-10,5	49,3	7,4
t15	Intervention	63,1	-2,8	32,5	-16,8
t16	Intervention	55,2	8,0	41,6	9,2
t17	Intervention	65,3	-10,1	35,8	-5,8
t18	Intervention	n/a	n/a	41,1	5,3
t19	Intervention	n/a	n/a	55,6	14,5
t20	Intervention	n/a	n/a	71,6	16,0
t21	Intervention	n/a	n/a	56,9	-14,7
t22	Intervention	n/a	n/a	57,3	0,3
t23	Intervention	58,1	-7,2	47,1	-10,2
t24	Post intervention	n/a	n/a	n/a	n/a
t25	Post intervention	55,3	-2,8	43,2	-3,9
t26	Post intervention	69,6	14,3	44,7	1,5
t27	Post intervention	70,4	0,8	59,9	15,2
t28	Post intervention	64,6	-5,8	43,0	-16,9