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CONTINUOUS PROCESS IMPROVEMENT METHODOLOGIES
APPLIED TO AN ENGINEERING EDUCATION SYSTEM

A Minor Dissertation Submitted in Partial Fulfilment of the Degree of

MAGISTER INGENERIAE

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ENGINEERING MANAGEMENT

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UNIVERSITY OF JOHANNESBURG

By

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ABSTRACT

Engineering education is considered to be a system. Most engineering education systems are under pressure to meet the demands set by its government. While a costly student throughput increase is possible, continuous improvement of the education system at all levels will be a more feasible and realistic approach. Within the operation management community a multitude of process improvement champions are competing for the attention of managers (and/or organisation leaders).

Each champion advocates the adoption of their improvement methodology. Almost all plead that if one can adopt their specific tools or follow a specific way of thinking; all operation problems can be solved. Most managers (leaders) are however still confused to select the best process the best process improvement methodology for their situation or system’s culture. In this research study several process improvement methodologies were evaluated and related to issues in an engineering education system.

The objective is to support heads of an engineering education system with strategic operation decisions to meet future demands. Working through the apparent conflicting claims of performance improvement programs, it was found to be critical to concentrate on the primary and secondary effects of these programs. Although each improvement methodology can contribute valuable approaches to an engineering education system, it is still found to be a challenge for leaders to define quality education and set targets for continuous improvements. The finding of this study illustrates that the various continuous improvement process methodologies can be utilised at various levels of the engineering education system (i.e. lecture, HOD, HOS). In order to fully maximise the effectiveness of the improvement methodology the system must also be transformed from the traditional engineering education system to a more innovative system which includes process improvement as part of its culture.
DECLARATION

I hereby declare that the minor dissertation submitted for the M.Eng (Engineering Management) degree to the University of Johannesburg, apart from the help recognized, is my own work and has not previously been submitted to another university or institution of higher education for a degree.

S.T. MABIZELE
September 2015
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CHAPTER 1

Study Overview

1.1 INTRODUCTION

The dawn of the twentieth century has been greeted with great technological feats being achieved by mankind; one can argue that these feats can be credited to the ideas and methodologies developed during the Industrial Revolution. These technological accomplishments have created what is today known as the global village (or globalization), whereby companies no longer only focus on domestic markets but now compete for a bigger slice of the pie in international/foreign markets in the pursuit of greater profit margins and most importantly to ensure that customer satisfaction is maintained and or constantly improved.

An inherent trait of globalization, is that it requires organizations (or businesses) to be competitive in the way they “do business” by improving efficiency, reducing cost, enhancing the quality of products or service (s), and an improvement in general business processes.

Customers now have a greater range of products and services from which they can select, which means organizations need to deliver a product (or service) of good quality at a reasonable price. To maintain a good level of customer satisfaction organizations need to be able to deliver good quality products (or services) at the promised cost, and on time to ensure an advantage against their competitors.

To maintain any advantage over competitors, organizations need to have continuous process improvement programs intertwined with their company objectives; this will breed a culture of improvement within the organization (Stormberg, 2009).

The purpose of any improvement process strategy is to achieve a better utilisation of all resources and reduce all waste associated with any process. Companies that survive, thrive, and grow are constantly changing and improving (Stormberg, 2009) . Process improvement entails focusing efforts in doing things in a more efficient and effective manner, rather than managing crises or “fire-fighting”.

Developments made during the industrial era, improved methods of manufacturing goods, management of systems and business processes within organizations. No matter the period
in time, businesses have and will always seek to constantly increase profit margins. In order to achieve greater profits changes had to be made, meaning factories had to be managed more effectively and efficiently.

The pioneers of the industrial era, such as Henry Ford (Ford Motor Company) utilised better manufacturing systems and processes to have the first moving assembly line, which gave Ford an advantage over its competitors and ensured business success. Ford built good quality cars at a cheaper production price and rewarded its factory workers with good wages.

Manufacturing has grown since the first assembly line, and as a by-product of the industrial era, trade has increased amongst nations. Thus organizations constantly look for ways to improve the way things are done to maintain and/or increase their market share.

Several improvement methodologies have been developed since the early 1990’s but most organization were wary of change, and often used staff reduction as a means of cost savings, this was however not an effective tool as it decreased employee satisfaction. Business Process Re-engineering was developed as a method to improve, redesign systems, and processes.

Methodologies such as lean, six sigma, statistical process control and theory of constraints are the currently widely used as improvement methods in the manufacturing and services industry. Highly competitive markets require advanced methods to be utilised and necessitate a culture of continuous process improvement to be in the fibre of any organization aiming to survive in the global market.

The objective of any organizations offering a product or service (s) is to eventually become a lean organization. Lean organizations are characterised by the minimal waste associated with their systems and processes. Lean organization endeavour to reduce (or eliminate) waste on a continuous basis, which reduce costs and can be translated to higher productivity and market share. Any continuous process improvements must always satisfy all customer needs.

System improvement can be accomplished in measuring three operational measurement parameters of a system, namely the following (Chase & Jacobs, 2004):

i. **Throughput**
   
   Throughput is the rate at which money is generated by the system through sales (Chase & Jacobs, 2004).
ii. **Inventory**

Inventory is all the money that the system has invested in purchasing things it intends to sell (Chase & Jacobs, 2004).

iii. **Operating expenses**

Operating expenses is money that the system spends to turn inventory into throughput (Chase & Jacobs, 2004).

The improvement of the above operational parameters will lead to financial gains in the organization, as that is the main aim of any system improvement initiative is to increase profit margins.

In preparing to implement any process improvement the capability and capacity of the system must be established prior to implementation. Capability is the organizations ability to produce the desired product as per customer requirements, a capability index ($C_{pk}$) is utilised to ascertain how well parts are being produced to fit within the specified range of design limits (Chase & Jacobs, 2004).

Process capacity must also be evaluated in conjunction with the capability of the system; capacity will ensure that the system has the ability to meet demand placed upon it.

Although many of the system (or process) improvement methodologies mentioned have traditionally been associated with the manufacturing industry, however many of the principles (or fundamentals) of the methodologies are transferable to the transactional (services) industry. This can range from sales and marketing, financial services, HR services, housing and planning. The key dissimilarity with the services industry compared to the manufacturing industry is that emphasis is placed on people and processes, rather than machinery, tools or systems.

Consequently focus is placed on measuring, systemising, and standardising processes whilst reducing variation (or defects) and turnaround times. The service thus becomes the product from the customer’s perspective; therefore customer focus becomes key to effectively map processes and managing them. Similar to manufacturing processes it is imperative to ensure that the correct variables are measured to prevent inapt system performance.
The purpose of this research is to evaluate current available methodologies and ascertain the viability of utilising one of the techniques in the case study presented in this paper. The case study will be based on Engineering Education considered as a system. A majority of engineering educations systems are under pressure to meet the demand set by its government. A costly student throughput increase is possible; however continuous improvement of the education system at all levels will be more feasible and realistic. Several process improvement methodologies will be evaluated and related to issues in an engineering education system. For the purpose of this study, students, government, and industry are the customers, whilst the university provides a service in the form of imparting knowledge and skills. Universities service the government and industry by producing (graduates) and conducting research for the betterment of society and mankind at large.

The research study will seek to aid managers of an engineering education system with strategic operation decisions to meet future demand.
1.2 PROBLEM STATEMENT

Similar to business organizations, governments are constantly on a quest to improve the economy of the country and enhance the lives of its citizens; this however requires skilled personnel in the engineering fraternity to drive infrastructure developments and manufacturing industries. This has resulted in great pressure being placed on engineering education systems to meet the demands set out by government in producing quality graduate students.

It is proposed in this research that improvement methodologies available be evaluated and verify if they can be applied in the Engineering Education System.

1.3 AIM OF THE STUDY

The aim of the research study is to investigate current available process improvement methodologies and, determine if system improvement methodologies can be applied to an education system. The investigation will establish a relationship between failures in developing a quality control system, and ultimately seek to aid education managers with strategic operation decisions to meet future demands.

The research objectives for the study are the following:

a) Investigate whether process improvement methodologies can be applied to the engineering education system.

b) Determine the relationship between failures to develop a quality control system

c) Support managers in the future decision making.
1.4 **OVERVIEW OF THE STUDY**

The chapter arrangement for the study is as follows:

I. **Chapter 2** is a literature review of *Process Improvement Methodologies* available and all associated facets related to process improvement.

II. **Chapter 3** is a discussion on the Experimental Setup and Design. A review of the research methodologies is also discussed.

III. **Chapter 4** presents experimental results based on the data collected.

IV. **Chapter 5** presents a conclusion and discussion of the research undertaken.
Chapter 1: Introduction
Problem Statement
Define objectives of the study

Chapter 2: Literature Review
Review available improvement methodologies:
Lean
Six-Sigma
Theory of Constraints
Statistical Process Control

Chapter 3: Experiment Setup
Collect System Performance Results
Analyse Data

Chapter 4: Findings
Key Issues
Proposed Solution

Chapter 5: Conclusion and Recommendation
Proposed Solution

*Figure 1.1: Approach used for the study*
CHAPTER 2

Literature Review

A literature review is given in this chapter pertaining to the various system improvement methodologies under study. Section 2.1 will discuss theory of constraints, lean production methodology is discussed in Section 2.2, and Section 2.3 will discuss Six Sigma and finally Section 2.4 will discuss Statistical Process Control as a final continuous process improvement methodology considered under this study utilised to drive any system improvements. It should be noted that the methodologies discussed here are from a manufacturing perspective however these are transferable to the service industry.

2.1 THEORY OF CONSTRAINTS

Theory of constraints (TOC) is an improvement methodology centred on the premises that all organizations are constrained by some limiting factor, hence the growth of all organizations is restricted, and they do not grow as large and rapidly as preferred by the organization’s leadership. The constraint limits the profit margins of a company or the output of system, otherwise organizations (or systems) would achieve infinite profits or products (Smith, 2000), (Ricketts, 2008).

For organizations to survive in the current competitive global environment organizations focus on the following factors:

- Increasing sales and market share
- Reducing cycle or lead time
- Increasing quality
- Reducing inventory
- Reducing cost (Smith, 2000), (Ricketts, 2008).

The methodology of TOC was developed by Dr. Eli Goldratt, and aims to aid in managing all constraints and achieving a good return on investments, by allowing managers to manage (or control) constraints or throughput rate of the system(s) to achieve greater profit margins for the organization. Constraint management is crucial as a constraint is the limiting factor of the organization, and affects the performance of systems.
According to Debra Smith the following ideology holds: “Either you manage a constraint or they manage you.”

The evolution of TOC started with a generic approach resolving factory (production floor) constraints and shifting the “bottleneck” outside the factory. Further development led to the Thinking Process (TP), which focuses on diagnosing and resolving problems (constraints) beyond the production floor. Thinking process entails the formation of logical trees which are cause and effect diagrams, starting with observed symptoms of problems, then cause and effect reasoning utilised to ascertain the underlying cause of problems (constraints). Other logical trees are used to identify and refine solutions and develop a step by step implementation plan (Smith, 2000), (Ricketts, 2008).

The final stage in the evolution of TOC is the Day-to-Day Thought Process tools which seeks to resolve problems causing “fires” amongst departments, the tools are aimed at improving the following:

a. Communication skills  
   b. Initiating skills  
   c. Empowerment skills  
   d. Team skills.

Although the TOC has evolved from the early work done by Dr. Eliyahu Goldratt, TOC is a tool that schedules manufacturing jobs by utilising limited facilities, machines, personnel, tools, materials and any other kind of constraint that would affect the organizations ability to adhere to a schedule (Chase & Jacobs, 2004).

The TOC approach is defined into a five step approach, namely the following:

1. Identify the constraint.  
2. Decide how to utilize the constraint.  
3. Subordinate everything else and focus on fully utilizing the constraint to the fullest extent.  
4. Evaluate the constraint to ensure improved productivity.  
5. Repeat the above steps by finding a new constraint to manage/improve (Smith, 2000), (Ricketts, 2008).
2.1.1 Drum-Buffer-Rope (DBR)

To adequately address any constraint, it is important to establish where the constraint/bottleneck is present in the system. A bottleneck can be defined as any resource whose capacity is less than the demand placed on it (Chase & Jacobs, 2004), this constraints the systems throughput. In a manufacturing process a bottleneck is where the flow thins to a narrow stream.

If no bottlenecks exists than the system is said to have excess capacity, and has a capacity greater than the demand placed on it. Thus to establish a constraint/bottleneck one must either run a capacity resource profile, or use plant/process knowledge to establish which resource is overloaded.

The drum-buffer-rope process seeks to exploit the constraint and provide a system with some form of control. The control process has been broken down into the following:

1. **Drum** is the constraint identified; it sets the “beat” or pace of a particular system or manufacturing operation. If any other operations outperform the constrained resource (drum), this only increases the expenses without improving the throughput of the system. Maximizing local resources (individual resources) results in a large work in progress inventories, and inventory does not generate revenue until it is sold, thus excess inventory on the shop/factory floor must be minimised (Smith, 2000), (Ricketts, 2008).

2. **Buffer** is all work scheduled on the constraint. The buffer is measured in time, and provides information about the system schedule such that it ensures that drum is always “beating” by ensuring that the constraint is always kept “busy”:
   - If all jobs ahead of the constraint are early or on schedule, the amount of work needed to keep the constraint busy is adequate meaning that the buffer is in the “green zone”.
   - If some jobs are behind schedule and will result in the constraint running out of work without any action, the buffer is said to be in the “yellow zone”.
   - If many jobs are behind schedule and it is clear that the constraint will run out of work without any action, the buffer is said to be in the “red zone”. This results in the upstream steps of the manufacturing process having to sprint to refill the buffer and keep the constraint busy, while downstream steps may have to sprint to finish late jobs (Smith, 2000), (Ricketts, 2008).
3. The **rope** governs when gating events should occur; the rope is classified into two categories:
   - Shipping rope – governs all work on the constraint needed to meet the market demand and keep the shipping buffer green.
   - Constraint rope – governs the release of all raw materials to commence new jobs and keep the drum buffer green (Smith, 2000), (Ricketts, 2008).

In essence DBR connects a rope between front end resources and the slowest resource in a production line (manufacturing process). The first resource can never outpace or overproduce the slower resource more than the length of the rope, if other resources are faster, they can sprint and close any gaps that might appear along the production line. This restrains all of the resources in front of the constraint (drum) to produce no faster, on average, than the constraint. The rope minimises all work in progress inventory in front of the constraint from growing beyond the slack allowed in the length of the rope.

Allowing slack in the rope, a protective buffer is established in front of the drum. The aim is to have a good due-date performance whilst minimizing inventories.

![Diagram of the drum-buffer rope technique](image-url)

*Figure 2.1: Illustration of the drum-buffer rope technique.*
In figure 2.1 a simplified representation of the drum-buffer rope technique is provided to illustrate how the technique is configured in a manufacturing process (production line). The constraint is ensured of receiving work through the inventory buffer with the rope linked to the input providing the process with constant material. The constraint identified in figure 2.1 is process “D” and reduces the output of the system because the process’s output cannot exceed what is produced by the constraint resource.
2.2 LEAN PRODUCTION

Lean production commonly known as “lean” is an improvement methodology that was developed in Japan as an enhancement of Just-In Time (JIT) manufacturing system/process. The fundamentals of lean are based on Kaizen (or rapid improvement process) which focuses on eliminating waste, improving productivity, improving quality products and reduce production costs.

The dawn of the globalization in the twenty-first century has resulted in increased competition in the market, it is therefore important that organizations account for all impacts of waste and aim to reduce it from the way in which an organization conducts its business, the objective of lean is to eliminate any waste which might affect the organization.

Since lean is based on Kaizen principles, continuous improvement is inherent within lean; its philosophy is that small incremental changes applied and sustained over a period of time will result in substantial improvements being made and gain a certain competitive advantage over other competitors.

Customers seek quality products which they are willing to spend money in acquiring them whether it is a product or service; this is defined as a value in the context of lean. Thus the aim is to reduce the expenditure of all resources and effectively utilize them in the process of creating value for a customer (Kruger, 2008). For organization to eliminate waste, all operation and tasks performed must be done so as to add value to processes and the organization in its entirety, the goal for the organization is to remove waste form all levels within the organization.

Defining waste is crucial prior to initiating lean, thus waste is defined as anything (activity, task or process) that does not create any value for the owner, client and customer (end user). Seven types of waste have been classified according to Taiichi Ohno, namely:

i. Overproduction (producing more than the demand)
ii. Waiting (waiting for the next step in the manufacturing processes)
iii. Transportation (moving products not required for processing)
iv. Processing (over processing as a result of poor tool or product design creating task)
v. Inventory (work in progress and finished parts not processed)
vi. Movement (people or equipment moving more than required to perform a task)
vii. Defective products (effort in inspecting) (Kruger, 2008).
More “wastes” have been suggested in supplementing the above, these include the following:

- human behaviour adding no value,
- complexity,
- dangerous working practices,
- excess information,
- figuring what to do or how to do it,
- making do,
- not speaking or listening,
- not taking advantage of people’s thoughts (wasting good ideas),
- not using peoples talents,
- underutilization of people’s skills and capabilities (Mossman, 2009).

As it can be seen waste is not absolute. For example some overproduction has value, as when a process is not yet capable of switching between products virtually instantly and yet customers want instant delivery; overproduction creates a temporarily necessary buffer; many customers value transportation to their door although they may not value transportation between work station in the factory.

![Quality vs. Cost](image)

**Figure 2.2: Lean methodology in relation to cost and quality**

Figure 2.2 illustrates the main objective of lean production/methodology, producing high quality products at a lower a lower cost with speed and agility (Kruger, 2008). This is the
ultimate goal of implementing lean techniques within an organisation, that is to reduce (or eliminate if possible) waste, reduce costs and improve quality of products and/or services.

2.2.1 Costs associated with waste

All waste contributes to costs being imposed to the organization in providing a product or service which the customer (end-user) values. Inventory cost is the most disconcerting cost, high levels of inventory can conceal deficiencies within processes, and deficiencies must be removed in the process rather than having high volumes of inventory. Holding inventory is a lost opportunity to generate profit.

Although some holding inventory places a burden on the organization, there are other costs to take into consideration, such as the following:

2.2.1.1 Carrying Cost (Cost of delays)

Carrying cost is a result of interruption in the process workflow, where raw materials are transformed into finished products. This process is called the transformation process. If products are transformed into finished products at a rapid rate, cost could be decreased.

Another component related to carrying cost is from idle inventory, which is products in storage; this cost can exceed the unit price of the product. Storage of any product for a given period of time requires a facility (building) to store the inventory. The storage thus requires insurance for the building and inventory, depreciation of inventory, spoilage/expiry of products, theft of products, lighting and security. Carrying costs are classified into three categories, namely the following:

- Raw material cost
- Finished goods cost
- Work in progress costs

2.2.1.2 Ordering Cost

Ordering cost is incurred when placing an order and receiving ordered items (or material) from a vendor. The size and frequency of the order determines the cost. The transportation and inspection of ordered goods is a component of ordering cost,
goods must be inspected to ensure quality goods are received and quality finished
products are delivered to customers.

2.2.1.3 Shortage Cost

Shortage cost occurs as a result of demand for a product outstrips the supply.
This can occur due to demand uncertainty and no inventory being available. The loss
in sales can also result in customers looking for an alternative supplier to provide the
desired products that they seek.

2.2.1.4 Actual purchasing Cost

Actual cost is incurred when buying materials (supplies) in bulk seeking a discount as
price per unit will be decreased; this cost is a consequence of the amount of
inventory held by an organization.

2.2.1.5 Idleness Cost

Idleness cost is a cost that results from any delays in processing of products;
idleness cost has the potential of decreasing customer’s satisfaction because delays
translate in customers not receiving their goods at the promised time.

2.2.1.6 Obvious Costs

Obvious costs are linked to capital costs and tied up to holding cost. A balance
between holding inventory and cost incurred must be maintained, little (or no)
inventory results in other cost and too much inventory results in capital cost being
incurred

2.2.1.7 Semi-obvious Costs

Semi-obvious costs are costs incurred due to material obsolescence and poor
inventory management. Cost associated with semi-obvious costs are the following:

i. Inventory planning cost

ii. Inventory keeping cost and physical counting of inventory.
Semi-obvious costs can be included in operating cost of an organization; obsolescence is primarily due to an organization being unable to sell products, which become superseded by improved products.

2.2.1.8 Hidden Costs

Hidden costs result from carrying costs and other related costs. A component of hidden costs can be due to management interference, as inventory would be released to the shop floor for a specific job but due to the interference the material would therefore remain idle until original job would be received. The idle material occupies valuable work space in factory floor. The idle inventory can accumulate into a big component of hidden cost.

Lean production seeks to eliminate or minimize the above cost through various techniques that include, namely the following:

- Lean thinking process,
- Value mapping, and
- Last planner system.

These lean techniques are discussed in detail in section 2.2.2, they all respectively have the potential to eliminate waste in processes and create a culture to performance aimed at reducing cost and increasing profit margins.

2.2.2 Lean Techniques

In the attempt to eliminate process waste there are several techniques that can be applied by an organization, namely the following techniques can applied:

2.2.2.1 Lean Thinking

There are five principles associated with lean thinking process; the aim of the process is to instil a philosophy that will ensure things are done in the correct manner to eliminate waste and create value for customers (end-users). The following principles are associated with lean thinking:

i. Identify Customer and Value – identify and define value for which a customer is willing to pay for, this aids in establishing a foundation for a value stream. By clearly
knowing the value, all waste (non-value activities) associated with creating valuable product can be targeted and removed from all processes.

ii. Identify and Map the Value Stream – map and identify all specific activities (tasks) required to eliminate all waste from conceptual design to end user. The value stream is all activities undertaken in delivering a product or service to a customer. Once it is understood what the customer wants it must be established how the product or service must be delivered to the customer.

iii. Create flow – once value stream has been established, all process interruptions must be eliminated ensuring the value stream “flows” to the customer without any interruptions.

iv. Customer pull – understand customer demands, and streamline products (or services) and processes to meet the customer requirements. This will ensure that products manufactured (or services provided) is what the customer wants and receives it when they want it.

v. Pursue Perfection – creating flow and pull begins with re-arranging all individual processes between the various steps of the value stream in eliminating all waste, the pursuit of the perfection requires doing all things right the first time through applications of continuous improvement efforts.

The above principles must be used in holistically across the organization to ensure that the improvement objectives are linked with the company's strategy. Processes must be constantly reviewed to ascertain if they are delivering value to the customer.
2.2.2.2 Value Mapping

Value mapping is flowcharting all steps, activities, material flows, communications and other process elements involved in the process transformation to deliver quality products or services. Viewing all steps to be undertaken to deliver good to a customer enables organizations to identify and target all non-value adding elements of the transformation process.

The first stage is to identify and target “Kaizen events” and collect information (i.e. measure overall quality, cycle time, scrap rate, etc.) on the targeted process. Second stage is to analyse all data collected and determine areas of improvement, observe and record all waste. The goal of the overall process and all the respective steps must be reviewing in the context of adding value towards meeting the overall objective of removing all waste.

Ideas are generated to eliminate the identified waste; ideas are tested to see if they work. New cycle times and throughput times are recorded, and overall savings are calculated from the elimination of waste.

The third stage is a review (follow up) to ensure that improvement is sustained and is not temporary. Performance must be routinely measured (using metrics) and documented, identify the need for possible modifications to sustain the improvement.

Team members (employees) must also be consulted in the review process to obtain feedback and suggestion. This is a feature of lean in that all team members (employees) are part of the solution and are encouraged to be improvement leaders in the respective areas of work.

2.2.2.3 Last Planner System (LPS)

The last planner system considers the “end result” in mind and all factors requirement essential to achieving the desired result. The first requirement for LPS is to start with the result (design, building, structure, product, etc.) that the organization or customer wants to create; this will in turn formulate all critical success factors and commitment to them in order to achieve the desired end result. It is important that all parties are committed and participate in attaining the desired value; all parties must become part of the solution.

The second component of LPS is to define the current reality in relation to the end result. Current reality contains existing assets within the organizations control. Understanding
available assets will make it possible to ascertain which assets must be reconfigured in progressing to the desired result. The ultimate goal is to turn current reality into something the customer will value; it must therefore be up to date as it might change during the improvement process.

Once the current reality has been established, necessary energy must be channelled in making sure all team members understand how and where to begin the improvement process. This leads to the fourth element of LPS which is to have an outline plan (milestone plan) which provides a holistic view of all the key milestones needed to reach the desired result. The outline plan is complemented by a detailed plan illustrating how to move from current reality to the desired reality.

The next element in LPS is to ensure learning culture is an inherent part of the process as it allows the opportunity to review effects of improvement actions and adjust current reality in pursuit of the desired results.

Considering the above process an organization must continue to Act-Evaluate-Learn-Adjust until the desired value is achieved. The end result must always be kept clear even when value changes or customer requirements change. Handover requirements must be clearly set out to aid in identifying problems before they become “fires”. LPS seeks to create value with a plan to achieve the desired goal whilst utilising the current reality to achieving the necessary improvement required (Mossman, 2009).
2.2.3 Lean Success factors

Lean is a performance based methodology seeking to increase (or maintain) an organization’s competitive edge over its competitors. The basis of lean is to introduce continuous improvement aimed at eliminating waste or non-value adding activities. The major challenge in employing lean production system (or methodology) is creating a culture of process improvement and maintaining long term commitment from senior management.

Before any improvement process can commence problems must be identified in every activity in every process. There are some pre-requisites which must be place prior to an organization considering a lean process improvement exercise, this includes the following:

- Clearly specify content and sequence in which tasks must be performed, the timing of tasks, and the desired result to be achieved.
- Internal and external customer connections must be clarified to ensure sufficient employee deployment, appropriate manufacturing method to be selected and timing of production.
- Simplify all manufacturing process flows to ensure the shortest possible route through all processes.
- Improvement process must be scientific in nature and be implemented at the lowest possible level.

In supplementing the above and ensuring a successful implementation of lean across the organization, listed below are some critical factors for a successful lean culture within an organization:

- Employees must be encouraged to think lean; every task must be viewed as being critical to the success of the organization. Waste must be eliminated through employee’s creative thinking with regards to work in their area of responsibility.
- Standard operating procedure (SOP) must be utilised to standardise all processes within the organization.
- Prioritise and maximize all value adding activities.
- Senior management support to ensure that improvement process is aligned with the vision and mission of the entire organization.
• Employee involvement at all levels within the organization so as to ensure that there is a common goal within the organization in relation to process improvement.

• Identify and rectify all dysfunctional processes, processes not functioning accordingly must be standardised using SOP’s.

• Adequate training is vital to make sure all employees become “lean experts” in their area of responsibilities

• Measurement of success is total product time

Successful improvements are measured by the sustainability of increased profits over a long period of time. The organization must endeavour to maintain the improvements made through lean techniques. A lean organization is characterised by having less friction between the reporting lines in the organization and allowing employees to take the lead in their respective areas of responsibility.
2.3 **SIX SIGMA**

All organizations desire maximum profits from all activities they are engaged in; however this requires integration of engineering design, material, and control strategies to ensure quality products are delivered to customers. Quality products require minimal variation in product process output. Six-Sigma (6δ) advocates the elimination of quality defects within a production process and business processes.

Sigma is a manufacturing process term, which is defined as a percentage of defect-free products from a production process. A six sigma is a process that produces 3.4 defects per million, thus 99.99966% products manufactured are free of defects. Sigma level numbers associated with Six Sigma represents the capability of a core business process, measured in defect per million opportunities (George, 2002):

<table>
<thead>
<tr>
<th>Sigma Level</th>
<th>Defects per Million Opportunities</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>3.4</td>
<td>99.9997</td>
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<tr>
<td>5</td>
<td>233</td>
<td>99.977</td>
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<td>4</td>
<td>6 210</td>
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<tr>
<td>3</td>
<td>66 807</td>
<td>93.32</td>
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<td>2</td>
<td>308 537</td>
<td>69.2</td>
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<td>1</td>
<td>690 000</td>
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A defect is any products (or services), or process that does not meet a customer’s requirement or may lead to not meeting a customer’s requirement. Six Sigma targets possible root causes of the variations in meeting customer’s requirements, and eliminate the defect opportunity. Defects are often the linked to a variation of some form, i.e. variation in materials, procedures, etc. Six sigma initiatives must have justified a financial target, which is to decrease cost and increase profit margins.
Table 2.1 illustrates sigma levels associated with manufacturing processes; a level of five (or higher) is the ideal goal for a Six Sigma improvement initiative. The six sigma methodology takes measurements at an early stage of the product or process development before variations occur in the production process.

Elements needed for a successful Six Sigma model/improvement initiative is the following:
- Customer satisfaction
- Financial results
- Management engagement
- Resource commitment
- Execution infrastructure

Six-sigma must be applied holistically within an organization starting from raw materials through to finished goods/products. Three objectives associated with the continuous improvement process must be achieved, namely the following:
- Increased profits
- Increased value
- Reduced variation.

The process improvement cycle associated with six-sigma is defined by the acronym DMAIC (Define-Measure-Analyse-Improve-Control), which can be broken into two processes, namely the following:

1. Process Characterization
   - Define project and process measurement (diagnosis)
   - Measure existing sigma
   - Analyse process data

2. Process Optimization
   - Improve and optimize process
   - Evaluate new sigma
   - Control and maintain process
2.3.1 Six-Sigma Analytical Tools

Analytical tools used in Six-Sigma have been used in traditional improvement programs for many years. However, their application in Six-Sigma is an integration of the tools throughout the entire organization’s management system. The tools include the following:

2.3.1.1 Flowcharts

A flow chart is a graphical or symbolic representation of a process. Each step in the process is represented by a different symbol and contains a short description of the process step. The flow chart symbols are linked together with arrows showing the process flow direction (Hebb).

Most flow charts are made up of three main types of symbol, namely the following:

1. Elongated circles, which signify the start or end of a process (Hill R.).

![Start](image)

2. Rectangles, which show instructions or actions (Hill R.).

![Rectangle](image)

3. Diamonds, which show that decisions must be made (Hill R.).

![Diamond](image)

The symbols are connected to each other by arrows indicating the flow of the process. A simplified process flow chart is illustrated in figure 2.3; this figure depicts how a receptionist routes incoming calls to the appropriate department within an organization.
2.3.1.2 Run charts

Run charts (or line graphs) demonstrate performance over a period of time. The charts illustrate the upward and downward trends, cycles, and any possible abnormalities which may be spotted and investigated.

Furthermore run charts afford the ability to track any improvements that might have been implemented are fruitful or not, and determine their success. An illustration of a run chart is presented in figure 2.4; the figure depicts the variation of inflation rate over time. The run chart illustrates the fluctuation of the inflation rate from the average of value of 4.5%.
2.3.1.3 Pareto charts (diagrams)

Any process improvement initiative requires data collection and identification of the frequency of each type of failure. Pareto charts are a graphical representation, which orders the types of defects or failure according to their frequency.

The Pareto chart is a vertical bar graph in which values are plotted in decreasing order of relative frequency from left to right. The chart is useful for analysing what defects (or problems) need attention first because the taller bars on the chart, which represent frequency illustrate which variables have the greatest cumulative effect on a given system.

An illustration of a Pareto chart is provided in figure 2.5; the chart represents complaints at a hotel over a period of one month. The complaints identified are: (1) waiting time for reservations, (2) room cleanliness, and (3) room service delivery time account for approximately 75% of all customer complaints during the period. The Pareto chart aids the leadership (or management) of the hotel in prioritising areas of improvements by first choosing an area (or complaint with the highest frequency.)
Check sheets are used to simplify data collection and analysis; they identify problem areas by frequency of location, type or cause. A check sheet consists of a list of items and some indicator of how often each item occurs. In the table 2.2, an illustration of a check sheet is presented to show how it is constructed to detect the occurrence of a defect (or error) in a process.

Table 2.2 Illustration of a check sheet

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Figure 2.5: Pareto Chart showing customer complaints (https://www.moresteam.com/toolbox/pareto-chart-service.cfm).
2.3.1.5 Cause-and-effect diagrams

The Cause and effect diagram (also called fishbone diagram) displays causes of any given quality problem, it effectively describes a variation in a process and the contributing causes by establishing the sources of variation. Once a defect error (variance) has been identified, it is isolated for further study to understand potential causes of the undesirable effect.

The diagram lists the problem (variance) at one end of a horizontal line; diagonal branches are drawn from the horizontal line for each major category of possible causes of variation. The contributing causes are added to the branch for each category, these branches represent sub-causes contributing to the variation. All contributing factors and their relationship are displayed on the diagram to visually aid in determining the source of variation in a process.

In figure 2.6 an illustration of a cause and effect diagram is given, the diagram depicted is from a plant producing raw material used as ingredients for copy machine toner. The plant experienced variation in resin output and a cause-and-effect diagram was constructed to determine the source of variation. Four causes contributing to variation are indicated, that is namely the following:

1. People: this entails variation occurring from human interface with machinery or incorrect set up of the machine, this can be regarded as human error.
2. Machines: all contributing sources of variation resulting from the machines used in the process.
3. Materials: all contributing sources of variation as a result of materials used in the process.
4. Methods: all contributing sources of variation as a result of the process methodology used to produce resin.

Each of the above mentioned causes are further analysed to determine their respective contributing factors towards the identified causes. A thorough understanding of a process is necessary prior to compiling the diagram; this will aid to ascertain if there are any special or common causes for the variation.
2.3.1.6 Control Charts

Control charts are aimed at reducing variability by monitoring performance over time; they also enable process corrections to prevent defects (problems/rejections) by trending and immediately detecting out of control conditions.

Typical control charts present a quality characteristic that has been measured or computed from a sample versus a sample number or time. The chart contains a centre line that represents the average value of the quality characteristic corresponding to the in-control state. Two horizontal lines are shown in the control chart; namely the following:

4. Upper Control Limit (UCL)
5. Lower Control Limit (LCL),

When all sample points fall within the limits, the process is said to be in control and no action is required. However if a point (or points) fall outside the control limit, it is regarded as evidence that the process is out of control, thus the cause must be investigated and corrective action (s) is taken to eliminate the cause (s) responsible for the out of control...
behaviour. Figure 2.7 provides a representation of a control chart illustrating a process operating within its control limits, the mean (average) is the dashed line in the centre, whilst the UCL and LCL are above and below the mean line respectively; the process would not require any adjustments as all observations lie within the process control limits.

Figure 2.7: Illustration of a Control Chart (Barry).

2.3.2 Six-Sigma Success Factors

Successful implementation of Six-Sigma establishes a culture of continuous improvement in an organization that becomes an inherent trait towards constantly delivering quality products (and services); the following are some success factors that are considered crucial for an organization looking reduce (eventually eliminate) variation from all process:

2.3.2.1 Customer satisfaction

The goal of Six-Sigma is to ensure customers are pleased with products or services delivered. It is important to know what the customer values the most; derive a value stream to deliver quality products or service. Quality of products or service is measured according to customer’s satisfaction. Six-Sigma drivers for customer satisfaction are the following:
- Voice of the Customer: What the customers say they want
- Requirements: Customer’s inputs are translated into specific measurable elements.
- Critical to Quality (CTQ): Requirements which are most important to customers.
- Defects: Failing to deliver to a customer's CTQ.
- Design for Six-Sigma: Designing products\service and processes based on customer requirements.

Gaps between what the customer wants and what the organization can currently deliver are areas where value can be created for both supplier and customer. Six-Sigma seeks to eliminate these gaps, increase operating profits margins, and aid organizations in going beyond subjective understanding of customer requirements to a specific requirements-driven process metrics. This will eliminate “fire-fighting” and establish a disciplined improvement based on customer satisfaction.

Defects in a process reduces quality, creates time delay, generate additional costs and results in loss of operating profit. Defects also pose a risk to CTQ and they must be addressed to improve quality, ensure less rework and scrap of products.

Customer satisfaction is vital in the competitive global environment where customers have a variety of suppliers to choose to provide a product or service; customer’s need must be satisfied for organization to their retain customers.

2.3.2.2 Financial results

No project or task is undertaken unless there is a sufficient and justifiable financial benefit to an organization. Six-Sigma defines financial benefits associated with any improvement exercise to be undertaken by an organization.

Organizations invest money in training employees on Six-Sigma (or other improvement initiative) to reduce waste cost associated with producing goods and, increase profits.
2.3.2.3 Management engagement

Management must not only just endorse but be fully engaged, as management has the responsibility of overseeing and guiding improvement incentives and ensuring that they are aligned with the organization's objectives.

Management must decide on which human resources to allocate and dedicate time for the training of employees, Six-sigma provides management with the advantage of seeing the explicit financial results associated with the improvement incentive.

2.3.2.4 Resource commitment

Commitment of personnel to Six-Sigma is roughly 1% of the organization's population. But more important than the number of people is the quality of the commitment. Personnel selected must be based on their potential of becoming future leaders of the organization (George, 2002).

Managers are faced with the dilemma on choosing which staff to devote towards the Six-Sigma initiative; however this is negated by appropriately selecting projects that are of most importance to the organization thus managers do not need to worry about losing their best employees due to improvement incentives as they will be adding value to important projects.

2.3.2.5 Execution infrastructure

Six-sigma possesses an infrastructure that effectively translates top management's objectives into customer orientated set of projects selected to maximise value and effective monitoring of results versus plan.

The infrastructure needed requires the following:

- **Champions** with the support of management to drive the goals of management to improve the financial performance of the organization.

- **Business unit champions** to identify value streams and prioritise projects based on net present value.

- **Customer CTQ** issues and time delays within the value stream must be developed into projects and prioritised.

- **Project sponsors** that own processes to be improved, they will have the authority to implement improvements and take long-term accountability for ensuring that the improvements and associated financial benefits are achieved.
Implementation stage requires a team approach; this requires a mix of team members. Black belts are team members who are fully devoted to improvement activities; green belts support black belt projects and are involved on a part-time basis.

A culture of improvements is vital for the success of Six-Sigma; a good culture of constant improvement within the organization will translate good strategies into good execution.

2.4 STATISTICAL PROCESS CONTROL

Statistical process control (SPC) is a process improvement strategy utilised for monitoring, managing, maintaining and improve process performance through the use of statistical methods.

SPC at its core seeks to improve the quality of products, and increase yield or maintain the current yield at a reduced cost (Wetherill & Brown, 1991). SPC effectively reduces product recalls, reworks, scrap rate, warranty costs, and improve customer satisfaction, increase market share, profit margins and productivity.

SPC utilises control charts to determine when a process is going out of statistical control and adjust it before it diverges out of the statistical limit. However the control charts do not present a clear picture as to what is erroneous within the process, it is therefore important that an appropriate measuring system be in place. Required data to be measured include process output quality, quality costs, process performance, etc. These lead directly to statistics, statistical methods can be applied to provide the following:

- Process behaviour through assessing quality levels of the process.
- Portray information as to when it is necessary to identify process variations and when not to look for them.
- Information where variation is likely to occur.
- Understanding of the operation of the system to aid in making process or product improvements.

The statistical results must be interpreted such that they can provide useful information on how to achieve quality products by appropriately adjusting the process where it is deemed necessary.
Quality control is classified into two categories; (1) inspection-based quality control, and (2) preventive-based quality control.

![Inspection-based quality control](image)

**Figure 2.8: Inspection-based quality control (Antony & Taner, 2003).**

Figure 2.8 illustrates a generalised overview of inspection-based quality control system. This control methodology is based on a traditional approach to manufacturing whereby production manufactures the product, and quality inspects a finished product to verify if they conform to customer specification. Inspection-based quality control only detects whether/when a product is not within specification, it does not provide any information as to what caused the defects or errors and how they can be corrected (Antony & Taner, 2003). Thus defective products will be produced prior to inspecting them; this will result in scrapping/ rework costs.

Inspection systems are not infallible, therefore there is always a probability that a good item can be rejected and a bad item be accepted. Purely evaluating products for a “pass” or “fail” is not informative with regards to continuous improvement of a product process quality (Wetherill & Brown, 1991). To overcome problems associated with inspection-based quality control, a preventive measure must be in place to ensure that quality goods are produced by a manufacturing process.
2.4.1 Statistical Process Control Success Factors

The following points are some important factors required for the successful implementation of SPC and creating value through SPC:

- **Top management involvement and commitment:** for any improvement to succeed there needs to be a step change in the way business is conducted. Management has the responsibility to oversee all improvements (or change) within the organization. Management needs to understand the potential variability-reduction through the use of SPC, thus they should be the first to receive SPC training. Thorough understanding of SPC will provide knowledge of all elements required for SPC, this will entail committing resources and providing the necessary training for successful SPC throughout the organization.

- **Training and education in SPC:** it is vital that the entire organization understand and is aware of SPC. The purpose of educating and training employees is to establish a culture whereby SPC is utilised as quality management tool, manage and reduce variation in production processes. Training should include exposure to relevant statistics, creation of control charts, types of controls, assumptions in chart theory and interpretation of charts. Training and education of SPC should entail constant follow-up training sessions over a long period of time (Wetherill & Brown, 1991), (Antony & Taner, 2003).

- **SPC implementation team:** for effective SPC roll-out a cross-functional team consisting of top management, a steering committee and a process team, SPC facilitator and quality engineer, quality manager, production manager, and purchasing manager, etc. The steering committee will be tasked with creating SPC awareness in the organization, provide necessary training and resources for SPC. SPC facilitators will co-ordinate the overall implementation of SPC (Antony & Taner, 2003).

- **Pilot study/cost-benefit analysis:** SPC requires a step approach by gradually applying its use to another process after one process has yielded good results. The feedbacks from the pilot studies are reviewed by the steering committee and management to assess the benefit of SPC. Cost analysis is crucial in the review of the pilot study as it aid in ascertaining the actual financial benefit to implementing SPC (Antony & Taner, 2003).
- **Measurement system analysis (MSA):** identifying, isolating and removing measurement variation would lead to improvement to the actual measured values obtained from the measurement process. MSA seeks to determine the variability accounted for by the measurement system for making measurements. This analysis checks if tools used to measure are adequate and fit for service (Antony & Taner, 2003).

- **Construction of control charts:** control charts are utilised to detect special causes of variation present in a process. The appropriate selection of control charts is thus important, the control chart should be constructed with the following in mind:
  - establish a suitable and responsive environment for action;
  - define the process where SPC must be applied and its link to other processes both upstream and downstream;
  - define quality characteristics (or process parameters) which needs to be measured, monitored, and managed;
  - define the measurement system and determine whether or not the current measurement system is capable to do its intended job;
  - understand the type of data and select a suitable control chart for the process.

- **Interpretation of control charts:** proper interpretation of control charts determine the ability to understand when processes are out-of-control and the reasons as to why a process is out of control, charts also provide the opportunity to immediately investigate the reasons for a variation in the process. An out-of-control plan can be established based on investigation of the process variations (Antony & Taner, 2003).

### 2.4.2 Types of Control Charts

There are four basic types of control charts which can be employed in SPC continuous process improvement methodology. The charts are further divided into two charts, namely the following

- **Variable charts:** utilised where measurements are taken of products to ascertain whether inferior quality was produced. Variable charts will be utilised for this investigation to understand the process variation and evaluate the stability of the process.

- **Attributes charts:** utilised to establish where data of inferior quality was recognised by counting the number of failings that occur (Wetherill & Brown, 1991)].
Chapter 2 presented a literature review of improvement methodologies considered for this investigation. The respective methodologies considered offer a variety of solutions to improving the system considered in this study, however they all advocate for improved quality with any improvement initiative.

Any methodology selected for any system (or process) improvement programme must elevate the system to a new level of operation. Improvements are generally characterised by a reduction in waste, improving flow and efficiency, whilst striving for a reduction in defective products. This therefore relates to quality management of the system.

Theory of constraints (TOC) was the first methodology considered as a starting point for the literature review. TOC focuses on managing constraints in the system which prevents it from functioning at its optimum operating level whilst improving the system throughput. An improved throughput rate from the system results in less inventory, equating to improved profits. However in the context of this study it would mean an increased number of graduates from the system and reducing the number of “work-in-progress” or “defects” which result from subjects in the curriculum being

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**Table 2.3 Four basic control charts (Wetherill & Brown, 1991)**

<table>
<thead>
<tr>
<th>Chart</th>
<th>Dimension</th>
<th>Dimension Controlled</th>
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<tr>
<td>Mean ($\bar{X}$)</td>
<td>Variable</td>
<td>Mid position of variable distribution</td>
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<tr>
<td>Range (R)</td>
<td>Variable</td>
<td>Range dimension of data diffusion</td>
</tr>
<tr>
<td>P</td>
<td>Attribute</td>
<td>Fraction of non-conforming products</td>
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<tr>
<td>C</td>
<td>Attribute</td>
<td>Number of non-conforming products present</td>
</tr>
</tbody>
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**2.5 SUMMARY**

Chapter 2 presented a literature review of improvement methodologies considered for this investigation. The respective methodologies considered offer a variety of solutions to improving the system considered in this study, however they all advocate for improved quality with any improvement initiative.

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failed by a student. The constraint(s) would therefore be subjects having the highest number of failures.

The second methodology reviewed focused on improving flow and reducing waste, this is the underlying principle of Lean Production techniques. It must be noted that attaining an engineering degree is a lengthy process and thus reducing the minimum cycle time of four years a student takes to complete their studies will remain unchanged. The engineering curriculum considered for this study entails two semesters (i.e. 2 semesters per year, thus 8 semesters in total for a four study period) for four years to complete the degree. Lean tools such as Value Stream Mapping and Seven Wastes must be utilised in the engineering education with the focus on reducing waste.

Quality products require minimal variation in product process output. Six-Sigma (6σ), advocates the elimination of quality defects within a production process and business processes. Sigma (δ) is a manufacturing process term, which is defined as a percentage of defect-free products from a production process. A six-sigma process, is a process that produces 3.4 defects per million, thus 99.99966% products manufactured are free of defects. The current sigma level of the education system must be computed and a new sigma must be target for the system.

Statistical process control (SPC) is utilised for monitoring, managing, maintaining and improve process performance through the use of statistical methods. SPC utilises control charts (similar to those utilised in six-sigma) to determine when a process is going out of statistical control and adjust it before it diverges out of the statistical limit. However the control charts do not present a clear picture as to what is erroneous within the process, it is therefore important that an appropriate measuring system be in place. Required data to be measured include process output quality, quality costs, process performance, etc. These lead directly to statistics, statistical methods can be applied to provide, (1). process behaviour through assessing quality levels of the process; (2). portray information as to when it is necessary to identify process variations and when not to look for them; (3).
information on where variation is likely to occur; and (4). understanding of the operation of the system to aid in making process or product improvements.

The statistical results must be interpreted such that they can provide useful information on how to achieve quality products by appropriately adjusting the process where it is deemed necessary. The use of SPC in the education system will allow monitoring of the students’ performance and provide the ability to adjust process to meet the desired results; this will also assist lecturers in identifying struggling students and provide an opportunity to develop more interventions to aid students pass.

The objective of any organizations offering a product or service (s) is to eventually become a lean organization. Lean organizations are characterised by the minimal waste associated with their systems and processes. Lean organizations endeavour to reduce (or eliminate) waste on a continuous basis, which reduces costs and can be translated into higher productivity and market share. Any continuous process improvements must always satisfy all customer needs.

In preparing to implement any process improvement the capability and capacity of the system must be established prior to implementation. Capability is the organizations ability to produce the desired product as per customer requirements, a capability index (Cpk) is utilised to ascertain how well parts are being produced to fit within the specified range of the design limits (Chase & Jacobs, 2004). Process capacity must also be evaluated in conjunction with the capability of the system; capacity will ensure that the system has the ability to meet the demand placed upon it.
Table 2.4 provides a comparative summary of the improvement methodologies considered in this investigation, all the methodologies have improved quality as a by-product of any improvement initiative.

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Principle</th>
<th>Objective</th>
<th>Focus Area</th>
<th>Assumptions</th>
<th>Continuous Improvement Cycle</th>
<th>Primary Result</th>
<th>Secondary Result (byproducts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPC</td>
<td>Process Control</td>
<td>Process to remain within control limits</td>
<td>Process</td>
<td>Control charts aid in keeping process within process control limits</td>
<td>Plan→Do→Check→Act</td>
<td>Uniform process output</td>
<td>Less Waste, Fast throughput, Less inventory, Improved Quality</td>
</tr>
<tr>
<td>TOC</td>
<td>Manage Constraint</td>
<td>System throughput capability meets demand</td>
<td>System</td>
<td>Speed and volume. Utilise existing systems and processes are interdependent</td>
<td>Identify→Exploit→Subordinate→Elevate→Repeat</td>
<td>Fast throughput</td>
<td>Less inventory, Improved quality</td>
</tr>
<tr>
<td>Six Sigma</td>
<td>Variation Reduction</td>
<td>3.4 defects per million</td>
<td>Reduce Span Variance</td>
<td>System output improves if variation in all processes is reduced</td>
<td>Define→Measure→Analyse→Improve→Control</td>
<td>Uniform and improved process output</td>
<td>Less waste, Fast throughput, Less inventory, Improved quality</td>
</tr>
<tr>
<td>Lean</td>
<td>Waste Reduction</td>
<td>No non-value activities</td>
<td>Flow/Service</td>
<td>Removal of waste will improve business performance. Small improvements are better system analysis</td>
<td>Identify Value→Indentify Value stream→Flow→Pull (JIT)→Perfection</td>
<td>Reduced flow time</td>
<td>Less variation, Uniform output, Less inventory, Improved quality</td>
</tr>
</tbody>
</table>
CHAPTER 3

RESEARCH METHODOLOGY

This chapter discusses the research methodology followed for the study investigation.

3.1 PURPOSE OF RESEARCH

The Faculty of Engineering and Built Environment at the University of Johannesburg was used as a case study for this investigation. The investigation seeks to evaluate available process improvement methodologies, and ascertain their viability in being applied to the engineering education system to increase the number of graduates (and reduce defects) produced by the system and its related processes.

The faculty offers engineering qualifications in two distinctive programmes, namely Engineering Sciences (B.Ing) and Engineering Technologies (Nat.Dip/ B.Tech). This investigation only focused on engineering sciences to limit the sample size of the data collected and analysed. The Engineering Sciences degree programme has three departments: Civil Engineering, Electrical Engineering and Mechanical Engineering, the respective qualifications are all offered as a four year degree programme.

The chronological performance of the entire system was measured using the student's Cohort data (i.e. 2001-2012); this was attained from the faculty’s database and thus formed the bases for the data to be utilised. The data was assumed to be accurate and valid as it was extracted from the faculty’s database, thus any possible biasedness was regarded void.

Any process improvement initiative undertaken by the Faculty must seek to provide a holistic solution to elevate the engineering education system under consideration to new operating heights. Small incremental changes have the ability to elevate the system to produce sufficient engineering graduates to meet the demand from government and industry.

The investigation utilises tools of the respective methodologies and illustrate their applicability to the engineering education system. The improvement methodologies considered in this study are often used separately in response to resolve any operational/production problems experienced by an organization. It must however be noted that a combination of the methodologies can be used such as in the case of Lean Six-Sigma to exploit the advantages of the two methodologies. This has widely been utilised to reduce defects (or variation) and improved the throughput rate. The improvement cycle from six-
sigma (i.e. DMAIC) will form the bases for applying the improvement methodologies to the education system.

Although In an attempt for rapid improvement, a conceptual model utilising available methodologies and their respective tools is proposed as a systemic and dynamic approach in resolving factors affecting the output of the engineering education system considered for this study.

### 3.2 TYPE OF RESEARCH

Research is process of collecting information, to enable researchers solve problems and\or acquire new knowledge to establish new principles or theories. Research methods are classified into two categories, namely the following:

1. **Quantitative research**: is a traditional approach to acquiring knowledge or undertaking an investigation requiring experiments to verify hypothesis. Quantitative research was utilised in this investigation to collect and analyse the data to validate the engineering education system’s performance.

2. **Qualitative research**: is an interpretive approach to investigating problems by going beyond empirical data, and involves observations, surveys and interviews. Qualitative was utilised in this study to evaluate process parameters in the system, conduct focus, and deduce from latest research on the current use and state of improvement methodologies.

Using of the research types described above provides a link between the data gathered and the premises for this investigation. It further enables the researcher to explore available methods to solve the problem identified (low throughput) related to the engineering education system whilst being able to draw relations to similar studies undertaken by other researchers.
3.3 RESEARCH METHODOLOGY

The objective of the case study is to explore the viability of utilising process improvement methodologies to an engineering education system. Kanakana et al. proposed a Lean Six-Sigma (LSS) framework to improve the throughput rate at the Tshwane University of Technology, South Africa. The work undertaken focused on utilising the Industrial Engineering Department as a case study, the results of were an improved throughput rate from 14% to 50%.

The work undertaken in this paper does not seek to alter the developed LSS framework, however it seeks to build on it and provide an alternative model (or thinking) that encompasses all the three levels (i.e. HOS, HOD and Lectures) of an engineering education in improving its performance. The tools of the various improvement methodologies (i.e. TOC, SPC, 6δ & Lean) will be applied to the respective levels of education system under consideration to illustrate the applicability of the tools in relation to the education system.

The work presented in this investigation will not include physiological or socio-economic reason for the decline in graduate engineers; these are regarded as being beyond the scope of this investigation. However focus group discussions (See Annexure C for Report) with practicing engineers were undertaken to gain an insight to their perception of the engineering education system and its ability to meet the demands from industry and government; the engineers were from different universities and had been enrolled for an engineering degree between the years 2000 to 2012. The work covered in this study is not limited to only the data provided by the University of Johannesburg, but applicable to other engineering faculties as the engineering education system is similar in all South African universities.

3.3.1 Research Constraints

The investigation involved utilising an Engineering Faculty’s student performance (final results) as a premise for the case study.

Constraints experienced in the investigation were the following:

- Availability of data to analyse from an Education system.
- Definition of quality in terms of an engineering education system.
• No prescribed outputs (results) from an engineering education system.
• No performance baseline for the education system
• No desired continuous improvement targets.

3.3.2 Assumptions

The following assumptions were made in this investigation:

• No performance baseline exists for the engineering education system.
• No curriculum changes have been made to the degree programme,
• The engineering education system under consideration is a 3 sigma process.
• Students have been in the system for at least one year as a minimum.
• Results are applicable to other South African Universities.

3.3.3 Data Collection and Analysis

Data utilised in this investigation was attained from the Faculty of Engineering and the Built Environment, at University of Johannesburg. The data contains academic performance of students enrolled in the faculty from the year 2001 to 2012.

The data was collected from the University’s database; it is noted that there was no practical method to test the accuracy and validity of the data, and it was assumed the data was valid and accurate as it was from the faculty’s database. Analysis was done on the entire data to mitigate any possible biasness on the part of the researcher and to ensure proper representation of the data is portrayed.

Probability sampling was selected as the preferred method of sampling for the purpose of Statistical Process Control method. This was accomplished through the usage of systematic random sampling framework.

The analysis will seek to answer the following questions:

1. What is the current performance of the engineering education system?
2. Where does the biggest variation (i.e. subject (s) with the highest failure rate) occur?
3. What is the average duration (years) it takes to process the product (graduate) through the system?

The above question will be addressed in chapter 4 through the application of the improvement methodologies in relation to the education system considered in this study.
### 3.4 SUMMARY

Chapter 3 describes and justifies the selected research methodology followed for this study. The chapter proceeds with a discussion on the purpose of the research undertaken and the rational utilised in this study. This was followed by a section discussing the type of research undertaken in this study.

The constraints identified in the research and assumptions made in relation to the study are discussed and provide the context in which they relate to the education system under consideration. The final section discusses the data collection and analysis as well the sampling methodology utilised.

In the next chapter the proposed application of the improvement methodologies to the engineering education system is discussed and illustrated through the use of the various tools from the methodologies.
This chapter discusses the application of process improvement tools and thinking in relation to the engineering education system.

**4.1 SYSTEM MODEL OVERVIEW**

The aim of any education system is to produce quality graduates into the industry (job market) to aid the government in its development goals, whether it is in *Science and Technology* or infrastructure development and other aspects of society. Alternatively others seek to become academics or devote their career to conducting research to find solutions to mankind’s problems.

The survival of an education system relies on attracting prospective students and ensuring a high output of students graduating from the system. It is noted that no system exists without any fault, thus the input is not always equal to the output of the system hence it cannot be regarded as functioning at its optimum level. Processes within the system need to be constantly evaluated and improved to eliminate any waste or abnormality associated with the performance of the system or process.

Similar to manufacturing operations, an engineering education system can be modelled as a transformation process as illustrated in Figure 4.1.

![Figure 4.1: Traditional Transformation Process Model of an Education System (Kruger, 2008).](image-url)
The transformation process enables managers with the ability to direct and control processes that convert inputs (resources) into a desired output (product or services); this is accomplished by adding value to the input(s) through a transformation process. The transformation process contains three components, namely the following:

- **Inputs**
  Inputs (materials or information) are entities used up in the process of creating goods or services, whilst others play a part in formation process however they are not used up. These can include staff/resources involved in the transformation process (or supporting it); buildings and facilities can also be viewed as inputs into a transformation process.

- **Transformation process**
  The transformation process is an activity or a set of activities that take inputs and transform them by adding value to yield a desired output for customers. It should be noted that in the case of an education system, people and information are inputs thus the nature of the transformation process may be less apparent to see.

  The overall transformation can be viewed as a macro operation, containing micro operations; an illustration of an engineering education macro operation is given in Figure 4.2.

![](image)

**Figure 4.2: Macro and micro operation of an engineering education system.**

- **Outputs**

  The output is the product of the transformation process; it may result in a desired or unwanted product(s) or service(s). In the case of this investigation it is to produce competent graduates (candidate engineers).
**Feedback**

The feedback loop provides information on the performance of the system, and thus functions as a control tool to adjust the inputs and transformation process to achieve the anticipated output.

To improve the education system under investigation the transformation process as depicted in Figure 4.1, needs to be altered to inherently incorporate improvement methodologies as part of the transformation process.

A transformation model incorporating continuous improvement must be developed and utilised by the engineering education system to improve the system output. To further assist in attaining improved results, the appropriate methodology (or strategy) from the vast techniques available must be selected for a specific improvement goal at the specified system level. This is depicted as an input into the transformation process to aid in accomplishing the desired output; that is a lean or a six-sigma (6δ) system or even a combination of both (lean 6δ).

A thorough analysis of the improvement techniques will be done to illustrate how they can be incorporated (or applied) in the education system under consideration in this study.
The proposed modified transformation process model incorporates continuous process improvement as a key input element to the transformation process, ensuring that the system consistently improves on its service offering to its customers; in this instance students and other stakeholders. The selection of the appropriate improvement methodology must be done with a specific target goal to be achieved within the system.

The improved system allows for continuous feedback from stakeholders (i.e. students, tutors, lectures, mentors, alumni, etc.) within the system, whereas the traditional model only considers feedback at the end of the process (i.e. output) which makes it hard to implement interventions to correct the faults (variation) within the system timeously. Continuous feedback enables for continuous process improvement and aids the system to proactively address any performance or quality issues affecting the service (or product) rendered by the education system. This further allows the system to have the desired output resulting from the improved system.

The system must always seek to be relevant in its course offering to retain its students, this necessitates that the student’s “voice” must be heard in how teaching takes place and aid in resources allocation to ensure academic success of students. It must be noted though that
the system can implement changes in the hope of improving results however students need to also play their role in ensuring their own academic success. A better relationship between the students and the education system must be established to ensure that the engineering education systems can response to the generational changes in their student. Students’ perception of the education system changes with time and thus the engineering education system must be receptive and dynamic to the changes in their students to remain relevant.
4.2 SYSTEM PERFORMANCE OVERVIEW

The performance of the system was evaluated (analysed) with the intent of answering the questions posed in section 3.3.3; all analysis was done utilising the data made available to the researcher to ensure objectivity and no biasness, for more details on the data please see Annexure A. The results of the performance review were attained using historical data from the systems through the use of the students’ final results for the various subjects offered in the curriculum.

Prior to improving any system it is necessary to understand the performance of the system prior to implementing any improvement strategies (or technique). The most simplistic way to evaluate the performance of the education system is to attain the graduate rate over a period of time, as this is the output of the system. It is noted that the system cannot be purely reviewed on the graduate rate; however this only gives a generic representation of the system’s performance and further analyses will be required to find failings within the system.

![Graph: Number of graduates over time compared to students enrolled in the faculty.]

Despite the progressive increase in student admissions (enrolment) to the faculty from the year 2001 to 2006 where the education system reached its peak in enrolments (i.e. 1448 students registered). The percentage of graduates (output) declined from 2001 (70%) to approximately 57% in 2006, which then increased to 60% in 2008. Post the year 2008 there number of registered students remained above 1000 pupils whilst the percentage of graduates has steadily decreased for the period post 2008. The graduating rate takes note
of the faculty as a whole; however it is also necessary to further break down the results into departmental performance within the engineering education system to establish if the decline in performance affects all the departments in the faculty or isolated to a specific department.

The performance of the respective departments within the system can thus be represented as a percentage of students that graduated against the students that were registered in a particular department for the corresponding year of study. Figure 4.5 represents the respective departmental performance for the period 2007 to 2012; this period was selected to review the performance of the respective department post the 2006.

![Graph: Departmental performance as a percentage of graduates.](image)

The performance of the respective departments reflects the overall general performance of the faculty as an entity; due to confidentiality the names of the departments are not disclosed in this study. The period 2006 to 2008 appears to be a transition period for the engineering education system, the system improved in attaining an increase in graduates during this period. However, post 2008 there has been a decline in the performance (i.e. graduates) across all the departments. The progress of the students through the transformation process must be considered to establish a clearer picture of the performance of the students. The transformation process is a minimum of four years, thus the system performance must be thus evaluated over a four year rolling period focusing on the percentage of students that exit the system as graduates at the end of four years and student retention within the four study period.
The rolling four year period represented by Figure 4.6 illustrates that the number of students within the engineering education system progressively decrease after the first year of study. The decline in student retention is evident for a rolling period of four years, this is shown by considering the 2005 intake of first year students was 421 pupils, yet after a minimum of four years (i.e. 2008) there were only 128 students registered for the fourth year of study, this translates to approximately 30% students retained by the system. In considering a manufacturing process the students are considered to be materials being processed through the transformation phase, a student failing a subject is considered a defect in the system. However it must be noted that failing students are not the only factor accounting for the slow progress through the transformation progress as students also drop-out of the degree programme.

The failure rate, which can be considered as defects within the system, is shown in Figure 4.7, the trend indicates a steadily increase in the failure rate (or drop outs/deregistering) of students within the transformation process. Inversely this equates to a decrease in the number of graduates being produced by the system thus this indicates that the system is under constraint in delivering graduates from the transformation phase as approximately 30% of students qualified to register for the final year (i.e. 4th year) of study.
In reviewing the failure rate it is important to note which subjects in the curriculum have the highest failure rate, this aids in understanding which subjects are affecting the output of the engineering education system and ensures that resources can be provided to alleviate the constrained subjects.

Subjects offered in the transformation process are micro-operations which students must pass through to move into the next processing phase. These subjects can be considered as non-performing (or defective) micro-process. Subjects with a high failure rate are provided by Table 4.1, a majority of the subjects were found to be in the first and second year subjects of study in the engineering education curriculum.

It is interesting to note that 55% of the “defective processes” were all engineering science subjects rendered by the Faculty of Engineering and Built Environment, whilst the remaining 45% were subjects offered by the Faculty of Natural Science (i.e. maths, physics, chemistry, etc.). These subjects are the upstream processes which require interventions to have more students progressing through the transformation process; the first year of study has an offering of 11 modules. A student must pass a minimum of 60% of subjects to be promoted to the next year of study; an interesting observation is that 55% of the defective processes in Table 4.1 are first year subjects.
There might be a variety of reasons as to why 55% of the first year modules are among the subjects with the highest failure, these can include but not limited to socio-economic factors, psychological distress, poor study techniques or the students inability to comprehend the work being thought and difficulty to respond to the demands of tertiary education. However these factors are not considered in this investigation as the premises of the research is to evaluate the feasibility of applying improvement techniques to system under investigation.

Table 4.1: Subjects related to non-graduating students

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sum of Pass</th>
<th>Sum of Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject G-1st year module</td>
<td>799</td>
<td>285</td>
</tr>
<tr>
<td>Subject E-1st year module</td>
<td>0</td>
<td>419</td>
</tr>
<tr>
<td>Subject F-1st year module</td>
<td>44</td>
<td>373</td>
</tr>
<tr>
<td>Subject C-2nd year module</td>
<td>0</td>
<td>1098</td>
</tr>
<tr>
<td>Subject A-2nd year module</td>
<td>0</td>
<td>1222</td>
</tr>
<tr>
<td>Subject I-1st year module</td>
<td>0</td>
<td>224</td>
</tr>
<tr>
<td>Subject H-1st year module</td>
<td>0</td>
<td>259</td>
</tr>
<tr>
<td>Subject D-2nd year module</td>
<td>422</td>
<td>873</td>
</tr>
<tr>
<td>Subject B-1st year module</td>
<td>0</td>
<td>1103</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>1265</strong></td>
<td><strong>5856</strong></td>
</tr>
</tbody>
</table>
4.3 APPLICABILITY OF STATISTICAL PROCESS CONTROL

Statistical process control is an improvement technique that uses statistical tools to aid management (leadership) in controlling and monitoring process variation. Variations are inherent in all processes; however, it is sometimes hard to identify their existence in the system or process.

In this investigation, variable control charts are utilised, these aid in ensuring process functions within its specified control limits. Based on the chart, it is possible to attain whether a process is “in-or out-of-control”. A control chart has been developed to illustrate the use of SPC; this is represented by figure 4.8 and is applied to a constraint subject (or module) within the engineering education system.

Since no statistical results were readily available, a subject (Subject “A”) from the curriculum was selected as a statistical sample to illustrate the viability of SPC being utilised to managed variation in a process. The constraint subjects are listed in table 4.1 and have been identified as defective processes in the transformation phase. It should be noted that a “subject/module” is regarded as a process in the context of the study.

Five samples (i.e., years: 2007-2012), consisting of 10 student performance results (i.e., 10 sampled items) were selected for a respective year (i.e., 10 students are sampled from each cohort year). Systematic sampling was utilised to derive the sample group. The process sample subgroups utilised are presented in table 4.2. The standard deviation was calculated from the samples. The standard deviation ($\sigma$) is denoted by the following equation:

$$\sigma = \sqrt{\frac{\sum_{i=0}^{n-1} (x_i - \bar{x})^2}{n-1}}$$  \hspace{1cm} \text{(Eq. 4.1)}$$

The standard deviation denotes the deviation from the mean of the data sampled; it provides the data cluster around the mean. The standard deviation aids in the compilation of the control chart, based on the standard deviation it is possible to derive control limits of the process utilising the following equations:

$$UCL = \bar{X} + z\sigma_x, \text{ and } LCL = \bar{X} - z\sigma_x$$  \hspace{1cm} \text{(Eq. 4.2)}$$

Where,

$$\sigma_x = \frac{\sigma}{\sqrt{n}}$$  \hspace{1cm} \text{(Eq. 4.3)}$$
\[ \bar{x} = \text{is the sample mean distribution for the standard deviation.} \]

\[ \sigma = \text{is the standard deviation for the process} \]

\[ z = \text{is the standard normal deviation for the sample} \]

\[ X = \text{is the mean of the sample} \]

\[ n = \text{is the sample size} \]

\[ UCL = \text{is the Upper Control Limit} \]

\[ LCL = \text{is the Lower Control Limit} \]

For the purpose of this investing it shall be assumed that the process is 3-sigma deviation process, thus \( z = 3 \). The data is considered to be normal distribution. The sampling mechanism utilised was preferred as it would identify the randomness in the variation, and if any non-random variation occurs, and possibly rectify the variance occurring.

**Table 4.2 Process Sampling Groups**

<table>
<thead>
<tr>
<th>Sample 1: 2007</th>
<th>( x )</th>
<th>((x_i - \bar{x})^2)</th>
<th>Sample 2: 2008</th>
<th>( X )</th>
<th>((x_i - \bar{x})^2)</th>
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<tbody>
<tr>
<td>1</td>
<td>61</td>
<td>8.41</td>
<td>1</td>
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<td>70.56</td>
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<tr>
<td>2</td>
<td>59</td>
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<td>3</td>
<td>42</td>
<td>259.21</td>
<td>3</td>
<td>57</td>
<td>1.96</td>
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<tr>
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<td>56</td>
<td>4.41</td>
<td>4</td>
<td>37</td>
<td>457.96</td>
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<td>76</td>
<td>320.41</td>
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<td>66</td>
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<td>213.16</td>
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<td>64</td>
<td>34.81</td>
<td>8</td>
<td>66</td>
<td>57.76</td>
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<tr>
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<td>47</td>
<td>123.21</td>
<td>10</td>
<td>68</td>
<td>92.16</td>
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<tr>
<td>( \bar{x} )</td>
<td>58.1</td>
<td>( \bar{x} )</td>
<td>( \bar{x} )</td>
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<td>1118.4</td>
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<td>( \sigma_{2007} )</td>
<td>9.9</td>
<td></td>
<td>( \sigma_{2008} )</td>
<td>11.15</td>
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<table>
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<tr>
<th>Sample 3: 2009</th>
<th>( x )</th>
<th>((x_i - \bar{x})^2)</th>
<th>Sample 4: 2010</th>
<th>( X )</th>
<th>((x_i - \bar{x})^2)</th>
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<td>( \bar{x} )</td>
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</tr>
<tr>
<td>( \delta_{2009} )</td>
<td>10.1</td>
<td></td>
<td>( \delta_{2010} )</td>
<td>12.07</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample 5: 2011</th>
<th>( x )</th>
<th>((x_i - \bar{x})^2)</th>
<th>Sample 6: 2012</th>
<th>( x )</th>
<th>((x_i - \bar{x})^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>3.24</td>
<td>1</td>
<td>39</td>
<td>302.76</td>
</tr>
<tr>
<td>2</td>
<td>57</td>
<td>77.44</td>
<td>2</td>
<td>52</td>
<td>19.36</td>
</tr>
</tbody>
</table>
Utilising Eq. 4.1 -4.3 and the sample subgroups above in table 4.2, the following results were computed for the process (Subject “A”):

The standard deviation for the process is thus computed as the following:

\[
\sigma = \frac{\sigma_{2007} + \sigma_{2008} + \sigma_{2009} + \sigma_{2010} + \sigma_{2011} + \sigma_{2012}}{6}, \therefore \sigma = 10.79
\]

\[
UCL = \bar{X} + z\sigma \bar{X}
\]

\[
LCL = \bar{X} - z\sigma \bar{X}
\]

Whereby,

\[
\bar{X} = \frac{58.1 + 58.4 + 50.7 + 50.2 + 48.2 + 56.4}{6}, \therefore \bar{X} = 53.67
\]

\[
\therefore UCL = 63.91, \text{ and } LCL = 43.43
\]

Based on the above calculated process control limits, a control chart illustrating the performance of the process (i.e. student results for the module). The control chart provides a pictorial view of how well the process performs. Figure 4.8 represents the performance of subject A for the period 2007 to 2012.
The control chart shows that the process (subject) has a lot of observations (variables) lying beyond the control limits, with 14 observations occurring below the LCL. There are 10 observations above the UCL. However, a majority of the observations are within the control limit but nonetheless, it is clear that the process is not in a state of control, and requires some form of rectification to ensure that the process is in a stable control.

### 4.3.1 Process Capability

Capability analysis is a measurement that indicates how well the process output conforms to the desired specification as per the limits of the system or process.

The performance of any process cannot only solely be measured by the use of control charts. It cannot be assumed that a process which is statistically in-control is capable at the same time. It is thus necessary to evaluate the capability of the process in producing products/outputs that are in accordance with the specification.

The capability index ($C_{pk}$) is a methodology that aids in determining the process performance. The index indicates whether the performance is closer to the UCL or LCL. The following equation is used to compute the Capability Index ($C_{pk}$):
Using the values ascertained in Section 5.3, the capability index is computed as follows:

\[
C_{pk} = \left[ \frac{\bar{X} - LCL}{3\sigma} \text{ or } \frac{UCL - \bar{X}}{3\sigma} \right]
\]  

(Eq. 4.4)

Taking the above into consideration, the UCL and LCL could be compared to determine whether the process is capable or not. The lowest ratio would determine the capability of the process, however as it can be seen the ratio is identical for the UCL and LCL with a ratio of 0.32. In order for a process to be capable a ration of at least 1 must be achieved, thus the process is currently not capable. Improving the capability of the system is therefore important to make certain that the system can improve its throughput rate and reduce its inventory, or the number of defects.

Improving the capability of the process will entail that the system (or process) variance is reduced within the education system; this will requires that the system performs within specified system limits. The data available does not give a picture as to where do the variance or instability come from, further investigation would be required to properly ascertain where is the system failing and a better usage of control charts be better utilised.

The use of SPC in relation to the micro-operations in the transformation can able better control of the process to attain a better process capability, SPC has the potential to identify variations occurring in the process at an early stage, and adjust accordingly. However, this will require that more interventions and variables are used to trend (or track) the performance of students in relation to the micro-operation under consideration (i.e. a specific subject/module). Feedback will therefore be essential between students and lecturers; this means feedback after a lesson or alternatively at the end of each section of the module covered from students must be implemented as an intervention for better results.

According to Kanakana et.al in her study at TUT it was evident that the time students spent studying contributed to their performance in tests and exams, therefore the time students spent studying affects their final results. Although it would be good to be able to trend the time spent studying and compare it to the performance as illustrated by figure 4.8 this was...
not possible for this investigation. Tutorials can aid in ensuring that a bare minimum of time a student spends studying a specific module, according to the study at TUT this came to approximately 90 minutes a week per module. It is often believed that students only spend time on tasks that contribute to their semester marks; however it is also imperative that students understand that the primary aim of attending any institution of higher learning is to study and attain knowledge, and a change in attitude is necessary to ensure the success of students.

SPC is best suited for monitoring and controlling a process; in considering the engineering education as a manufacturing system, SPC can be an effective tool which lecturers can utilise to decrease the defective products or any variation in the process. The average test (or exams) result of students does not provide an adequate performance evaluation of students and failings within the process.
4.4 APPLICABILITY OF THEORY OF CONTRAINTS

Section 2.1 provided a literature review pertaining to Theory of Constraints (TOC), this methodology (TOC) aims to improve the throughput rate of a system (i.e. transformation phase in the context of this study), whilst reducing inventory within the system. TOC stresses that all organizations (businesses) exist to make a profit, however all organizations are limited by a certain constraint and proper management of the constraint leads to success.

Figure 4.1 and figure 4.2 indicated a clear decrease in the throughput of the engineering education system in this case study. In figure 4.9 it is seen that the duration period of the transformation process (average duration) to produce an engineering graduate (product) from the system is on a steady increase, indicating that the system has a lot of “work-in-progress (WIP)” or inventory within the system. As a result the system’s throughput is on a decrease and therefore the system is constrained in producing graduates within the minimum period of four years.

Figure 4.9: Average duration to complete engineering degree.

The average time taken by students to complete the engineering degree and graduate from the system can be further broken down to illustrate the number of years most students take to complete their studies.
It is noted that four years is the minimum number of years it takes to graduate (i.e. complete studies), but it was considered that students from other institutions get some subjects (or modules) exempted as well as students who change engineering disciplines affect the student count. These students were thus considered as outliers for the purpose of the analysis, the analysis further takes notes that data from earlier years was not available which affects the average years it takes to complete the degree for some students.

Table 4.1 presented subjects which have affected the throughput of the system, this comprises mainly of subjects in the first and second year of study within the engineering education system curriculum. Figure 4.11 considers the transformation process as a macro-operation with micro-operations at each stage of transformation, and also takes note of the flow of material (i.e. students) to produce engineering graduates.

![Figure 4.10: Time taken by most students to complete the degree.](image)

![Figure 4.11: TOC Applied to Engineering Education System](image)
Students which have failed some subjects which are not prerequisites to proceed to the next stage of transformation continue and are noted as Work-In-Progress (WIP), these can be regarded as inventory in the system. In reviewing the engineering education system, the constraint(s) is identified as subjects in the second year of study. The following equation is derived to compute the throughput of the system, whilst noting that the second year is a constraint:

\[ \text{Bottleneck Throughput}_{(yr-3)} = \text{Throughput}_{(yr)} - (\text{Failures}_{(yr-3)} + \text{Failures}_{(yr-2)} + \text{Failures}_{(yr-1)}) \]

whereby,

- Throughput \(_{(yr)}\) = total students (i.e. 2012)
- Failure \(_{(yr-1)}\) = 4\(^{th}\) year failures (i.e. 2011)
- Failure \(_{(yr-2)}\) = 3\(^{rd}\) year failures (i.e. 2011)
- Failure \(_{(yr-3)}\) = 2\(^{nd}\) year failures (i.e. 2011)

It can be seen from the equation that the throughput of the bottleneck limits the systems throughput. Time lost by the bottleneck cannot be regained, thus a balance must be attained to reduce inventory (i.e. students failing) within the system whilst improving (increasing) the throughput of the system.

It is crucial that the current system must be assessed prior to commencing with any attempt to improve its. Clear objectives of the improvement goal must be well defined prior to commencement of improving the output of the system.

Further analysis of the constraints identified; that is subjects with a high failure rate in the second year, will lead to a proper understanding of the bottleneck and the cause of the constraint(s) in the system.

Utilising the five premises of TOC, the constraints in the education must be resolved to ensure a profitable and high performing system. The WIP in the system require attention so as to enable proper efficient use of resources, and further financial support, and monitoring will be required to efficiently manage the bottleneck.
To surmise TOC, the following will need to be reviewed pertaining to the case study under consideration:

- **Identify**

The constraint has been identified to be the second year of study in the education system; this is subjects/module (process) which experienced a high failure rate in the transformation process.

- **Exploit**

A strategy must be developed to overcome the constraint; this must make certain that the bottleneck is manipulated such that the throughput rate of the bottleneck is increased (or improved).

Strategies to be explored might involve allocating extra resources (quality lecturers, more tutorials or private tutorials) to alleviate the bottleneck. Alternative teaching methods and supplementary educational resources utilising the internet (and or social networks) could also be explored, and having more interventions to evaluate the progress of student, this can include group presentations of the work covered for a particular period.

Pre-determined performance measurements for the system must also be reviewed and account for the entire inventory within the system as well as its effect on operating expenses in relation to the output of the system. Cognisance must be taken that if the system has any excess inventory, it will indicate a possible excess capacity within the system which should be exploited as well.

- **Subordinate**

All available resources must be focused around the strategies developed to resolve the constraint identified. The resultant strategies must still enable all other micro-processes (i.e. 1st year, 3rd, 4th year of studies) in the transformation to perform at the same output rate as the bottleneck throughput.

Mentoring programmes amongst senior and junior students could be established to have better synergy within the system, and improve the process flow throughput. Study methods
and practical skills from senior students can aid in knowledge and skills transfer to aid struggling students.

- **Elevate**

The capability of the system (or process) must be improved to mitigate the influence of the constraint within the system or process. The performance of the constraint must be elevated to higher levels by improving the capacity of the process at the bottleneck.

- **Repeat**

As soon as the identified constraint (i.e. 2nd year study modules) has been resolved (or eliminated), the “TOC process” must be repeated to focus on other constraints affecting the system. This therefore necessitates that TOC be applied on a continuous basis and becomes part of the organizations culture towards improvement in all facets of the organization, in this instance it would be the system under consideration.

The constraints are divided into two categories, which are tangible and non-tangible. Systems, processes, labour, raw materials, equipment and machines are classified as tangibles constraints, whereas non-tangibles can be classified as training, policies, and procedures.

The profitability of an organisation is measured through three categories, namely the following:

1. Throughput rate
2. Inventory
3. Running expenses

The aim of TOC in the study under consideration is to improve the throughput rate of a system and ensure a higher number of graduates being produced from the system. In any manufacturing system it is be ideal to pass products through the process/system in the shortest time possible, thus failures (i.e. defects) in the education must be minimised enabling the system to produce a high number of graduates in the specified minimum of four years.
The application of TOC in relation to the engineering education system must be applied to resolve the bottlenecks from a system perspective, the TOC strategy employed must be linked to micro-operations discussed in Section 4.3. Silo operation must be discarded to ensure synergy within the system to ensure bottlenecks are minimised. TOC can afford the system under investigation the ability to provide direction at a sub-system level in resolving process deficiencies in micro-operations identified as constraints affecting the output of the system.

Resources need to be made available to allow for these bottlenecks to be resolved, and develop policies that will allow the system to better handle and resolve identified constraints. TOC has the potential to allow leaders in the engineering education system to be more proactive in identifying and addressing constraints. In order to fully maximise the effectiveness of TOC, it must be implemented at a Head of School (HOS) operating level to ensure that from an organisation’s perspective it is good to have senior leadership is actively leading the charge for change and improvement rather than only requesting it from lower operating levels of the engineering education system. Leadership that actively drive change and improvement creates an inherent culture for improvement within the organisation and ensure a shared goal for improvement and better results from the engineering education.
4.5 **SIX-SIGMA**

The Six-Sigma ($6\sigma$) improvement methodology postulates an elimination of any variation in the process (or system) by an organization in delivering a product (or service) to a customer. In this case study, this means a reduction in variation within the education system and an increase in the output of graduates being produced by the system.

As illustrated in figure 4.4, figure 4.5 and figure 4.7, it can be seen that there is some variation within the education system. In an effort to analyse and reduce the variation it is important to briefly define quality.

According to ISO 9001, quality is defined as the following:

- Fit for purpose,
- The standard of something as measured against other things of similar kind,
- The degree of excellence of something
- The general excellence of standard or level.
- Meeting the needs and expectation of customers

Equation 4.1 was utilised to compute the standard deviation of a process in Section 4.3, this equation is can be modified and utilised in six-sigma to reflect $6\sigma$ process, and this is shown through equation 4.5:

$$6\sigma = \sqrt{\frac{\sum_{i=0}^{n-1} (x_i - \bar{x})^2}{n-1}} \hspace{1cm} (Eq. 4.5)$$

The above equates to 3.4 defects per million, resulting in 99.9997% defect free products. The analytical tools utilised in six-sigma are similar to those of the SPC process improvement methodology. Utilising the analytical results attained in section 4.3, a six-sigma process would result in the following if applied to in this case study:
\[ \sigma_{2007} = 9.90 \]
\[ \therefore 6 \sigma = 9.90, \sigma_{2007} = 1.65 \]

\[ \sigma_{2008} = 11.15 \]
\[ \therefore 6 \sigma = 11.15, \sigma_{2008} = 1.86 \]

\[ \sigma_{2009} = 10.10 \]
\[ \therefore 6 \sigma = 10.10, \sigma_{2009} = 1.68 \]

\[ \sigma_{2010} = 12.07 \]
\[ \therefore 6 \sigma = 12.07, \sigma_{2010} = 2.01 \]

\[ \sigma_{2011} = 10.87 \]
\[ \therefore 6 \sigma = 10.87, \sigma_{2011} = 1.81 \]

\[ \sigma_{2012} = 10.66 \]
\[ \therefore 6 \sigma = 10.66, \sigma_{2012} = 1.78 \]

The standard deviation for the process would thus be computed as the following to reflect a six-sigma process (or system):

\[ \sigma = \frac{\sigma_{2007} + \sigma_{2008} + \sigma_{2009} + \sigma_{2010} + \sigma_{2011} + \sigma_{2012}}{6} \]
\[ \therefore \sigma = 1.7983 \approx 1.80 \]

This would thus aid to derive the control limits for the process, the UCL and LCL to develop a control chart for the process would be computed as the following:

\[ UCL = 55.37 \]
\[ LCL = 51.96 \]
\[ \bar{X} = 53.67 \]
Figure 4.12: Six-Sigma applied to control chart for Subject “A”

It can be seen from the above chart that the process has a lot of variation, which will need to be eliminated and ensure process performs within the specified control limits. The cause and effect diagram can shed some light into what is causing the current variation within the process; however it should be noted that this is beyond the scope of this current study.

The quality requirements must be clearly defined to enable better control of the process variation and allowing the organization to perform as a six-sigma institution consistently delivering quality products (i.e. students). The results considered for six-sigma thus far are what would be expected if the results attained in section 4.3 (i.e. SPC) were to be modelled as a six-sigma process.

The continuous process improvement cycle for the six-sigma is defined by the acronym DMAIC, this is Define, Measure, Analyse, Improve, and Control. The improvement cycle this case study could only be applied up to the “Analyse” phase as a pilot project would need to be completed to effectively illustrate the effectiveness of six-sigma. However utilising the study by Kanakana et. al. it can be seen that six-sigma is an effective toll which can improve the throughput of the education system. It must also be noted that the study at TUT utilised lean six sigma, as it preferred choice for process (or system) improvement.
For the purpose of this study the following summation can be made in relation to six-sigma and how it can be utilised by the engineering education system:

- **Define Phase**

The definition phase provides the objectives of the process improvement initiative to be undertaken. It must clearly define the all stakeholders to be involved, the scope of the improvement initiative and all deliverables, team members, sponsor and timelines to be utilised. This is often done as a project charter.

The definition for this case study was outlined in chapter 1 of this investigation; in essence it seeks to increase the throughput rate of the engineering education and identify the relationship between the failures of students to the throughput rate. This would in term mean improving the current operating sigma level of the education system, a minimum sigma level of 3 would be considered as a good benchmark and if the system is below this sigma level, it would require the system to reduce defects or variation in the system. A business case would also be developed in conjunction with the project charter, according to Kanaka et. al the faculty losses approximately R 30 481.49 in potential income per student when they repeat a subject/module, this further has a knock-on effect with available spaces for new students at the faculty (or University). This therefore compounds the strain placed on the engineering education system in producing graduate engineers as there is limited space for allow potential students to study engineering.

- **Measure Phase**

The measure phase entails determining the current sigma level performance of the system and elevating it to a new improved sigma level. The system’s sigma level was determined utilising the percentage yield of students graduating from the faculty.

The system sigma level in the year 2001 was determined to be approximately 2.033; this declined to a sigma level of 1.670 in the year 2006 the sigma, whilst there improvement (recovery) in 2008 for the system to achieve a sigma level of 1.781 in 2008. The sigma level progressively declined year on year post 2008 to a sigma value below 1 for the year ending 2012.
The cost of poor quality, which is linked to students failing subjects according to Kanakana et. al is classified as the following for the engineering education system:

1. Internal failure costs: Costs incurred as a result of an error detected before the output was accepted by the customer’s organisation. This cost is incurred because not everyone performed their job correctly the first time (i.e. students failing a subject)

2. External failure costs: Costs incurred as a result of customer’s receiving products or services which do not meet the desired specification. These costs are incurred when appraisal techniques (or tools) fail to identify all errors (or defects) before products (or services) are rendered to a customer (i.e. government grants or industry funding).

3. Prevention costs: Costs incurred in an effort to prevent errors (defects) from occurring, these are costs related to aiding employees to do the correct job the first time around. This can be regarded as a future investment (i.e. training, tutorials, mentorship and counselling).

4. Appraisal costs: Costs arising from completed outputs and auditing the process to measure conformance to the customer requirements in an effort to establish criteria and procedures. This cost is incurred to verify if an activity (or task) has been done correctly the first around (i.e. quality audits, proof reading and moderation).

In the case study under consideration these costs could not be quantified as access to financial records (grants and funding) was not possible, however these costs can be calculated by the leadership or those with delegated authority within the faculty. Identification of the above mentioned cost will aid the leadership to direct improvement initiatives within the engineering education system (Kanakana, Pretorius, & Van Wyk, 2014) and allocate the appropriate resources to ensure that the system functions at its optimum level of operation. The leadership of the education system must also endeavour to improve the sigma level of the system by increasing its output.

- Analyse Phase

The analyse phase, entails focusing efforts into reducing identified variation in the system’s output and reducing (eventually eliminating) any non-value adding processes in the system. Since no possible interviews were conducted with students to account for their performance in relation to the engineering education system. The study was thus limited to the
performance results of the students which reflects the state of engineering education system under consideration

Utilising the findings from TUT by Kanakana et. al, and drawing relations to the engineering education system at University of Johannesburg, the following causes of variation were identified:

1. Student subject/module failure.
2. Student dropout.

It is noted that the variation in the system is not only limited to the above mention sources of variation. Section 4.2 highlighted that if one considers the student intake (1st years) in 2005 only 30% percent were registered for their final year (i.e. 2008), this is after a minimum period of 4 years of study. This means the faculty does not retain 50% of their students which also accounts for the low throughput rate.

It was also noted in section 4.2 that the bottleneck of the system occurs between the first and second year of study, with subjects in these years of study accounting the most for the constraint in the system. There might be deeper reasons to the students’ failure besides the inability to comprehend the module taught by the lecturer, it could be argued that the lecturer (s) also contributes to the failure rate in the perhaps the teaching style does not suit the students or language barrier between students and the lecturer (or language barrier from the students’ perspective in engaging with the module).

The structure of the engineering education system also constricts the flow of students in that there are prerequisites in some subjects/modules, therefore if a student fails a subject they cannot progress to the next level for further processing in the transformation. Further analysis should be considered in analysing the respective performance of the departments within the faculty, the current study did not measure the sigma level of the respective departments, and it only considered the overall sigma level of the education system. In applying the analyse phase it would also be prudent to conduct focus groups with students (and also one on one interviews) to try understand the difficulties experienced by students. Students need to be profiled in order for the faculty to better understand how to support students to achieve better academic results to help improve the number of graduates within the minimum specified time of four years. A cause and effect for students failing subjects is provided in figure 4.13.
The cause and effect diagram notes four contributing causes (source of variation) to students failing a subject, namely the following:

1. Environment
2. Materials (subject material)
3. People
4. Facilities.

Although students differ from University to University, this was considered as a fair reflection as all engineering degrees are similar in South Africa.

Figure 4.13: Cause and effect for students failing subjects/modules (Kanakana, Pretorius, & Van Wyk, 2014).

- **Improve Phase**

The objective of the improve phase is to improve the current operation of the engineering education system; this entails reviewing system procedures and processes, and reviewing policies to establish where improvement can be made. The engineering education system is a lengthy process thus it'll take a long period to see sustained changes and improvements in the system.
The understanding of where the variation occurs as defined in the Analyse Phase will enable for intervention to be established to eliminate (or reduce) the occurrences of such variation. The identified subjects noted as constraints, will need attention to from the faculty and additional resources to eliminate the variation in the system resulting from the failures. The identified subjects were found to be those in the first and second year of study. Entrance to the engineering programme is based on high school students meeting the requirements set out by the faculty for eligibility for enrolment. The orientation programme for first year must also be reviewed to ensure students fully understand the demands of the engineering degree. More effective tutoring sessions and mentoring need to be established as part of the improvement initiative to provide additional help to students, the improvement strategy should further allow the engineering system to identify struggling students at an early stage and provide them with the additional help they might need for successful results and ensuring that students complete their studies within the minimum study period.

In reviewing the progress of students over a period of fives it was evident that retention of students from 1st year to the 4th was low with only approximate 30% of students making it to the fourth, it should be noted that the 30% only took account of students registered and does not take not of students repeating subjects. No changes can be made with regards to the duration however the system must be dynamic to deal with the changes in students, generational changes must also be reflected in service offering from the education system. Curriculum changes not the education system at high school level must also be considered as a factor accounting for students’ readiness to tertiary education.

The improvement strategy to be implemented by the engineering education system considered in this study must seek to reduce subject failures, maintain an optimum retention level of students (i.e. approximately 50%) to allow the system to improve its throughput rate and delivering graduates to meet the demands of the government and industry, an important factor (or variation) is the dropout rate of students from the engineering education system. Dropouts were not thoroughly examined in this case study as the might be a range of factors which resulted in students dropping out, these include but not limited to voluntary dropout, academic exclusions due to students failing, psychological factors, socio-economic factors and financial exclusion of students.

The quality of students must be classified with a tangible measure to allow the system to better understand the inputs into the engineering education system, further to this, the
students already in the system affect the quality of the system. Another consideration which was not explored in this case study is the impact of student to lecturer ratio; this affects the interaction and engagement between student and lecturer. Large classes make it impossible for adequate interaction between lecturers and students. Kanakana et. al. modelled a ratio of 1:40 was preferred (Kanakana, Pretorius, & Van Wyk, 2014), however this would need to be reviewed to suit the specific engineering faculty as not all Universities have the same numbers in terms of students and lecturers.

- **Control Phase**

The control phase entails standardising improvements made in the Improve Phase; this will entail establishing a new way of doing things. Improvements made need to be maintained to ensure that the faculty achieves targets set out by the define phase of the DMAIC cycle. Changes to the system may result in personnel movements or adjusted to meet the demand (Kanakana, Pretorius, & Van Wyk, 2014).

The process parameters may require to be changed in order to reduce the variation and thus operations need to be standardised, standardising the new established process will entail the following practices to be implemented:

1. Process control: used to monitor process variation and controlling process input parameters leads to minimum process variation.
2. Control plans: used to define the method of control and minimise any potential variation.
3. Work instructions, procedures, process flows and flow charts: used to document process procedures and responsibility.
4. Training of process personnel: training is done to enable personnel to understand their new responsibility (Kanakana, Pretorius, & Van Wyk, 2014).

The engineering education system unlike other manufacturing processes has a long lead time for products to move through the transformation process. It is therefore essential to allow enough time to see the impact of changes made to the system; the improvement must be monitored for a minimum period of two years (Kanakana, Pretorius, & Van Wyk, 2014) (Kanakana, Pretorius, & Van Wyk, 2014). However the process must be monitored on a continuous basis to see the benefits of the improvement initiative. A control dashboard
showing all important parameters in relation to process variation within the education system must also be developed to communicate all crucial information to the leadership (and process owners) to justify the project and allow them to make any necessary adjustments to ensure that the project achieves its intended targets.

An important part of the control phase is to document all lessons learnt, this will provide guidance for any future projects which might be considered at a later time. It is also important to keep this document to ensure that the faculty is a learning organisation. All organizations exist to make a profit thus any financial gains or savings must be recorded to justify the implementation of any improvement project.

A new and improved system aids the faculty in being competitive and relevant in attracting students, whilst maintaining a good working relationship with industry and government. The mentorship programme must also be formalised to evaluate its benefit both to mentor and mentee.
4.6 SUMMARY OF RESULTS

This chapter presented how the various continuous process improvement methodologies can be applied to the engineering education system. All the improvement techniques have the potential to reduce process variation occurring in the transformation phase of the engineering education system. The reduction of the process variation should lead to an improved system throughput and produce a high number of graduates. It was noted that the system has a low retention of students between the first and fourth year of study, this must be improved.

The improvement project must seek to address the challenges faced by the system, it is thus necessary for the leadership of the faculty to focus on the changes that will improve the stature of the engineering education system. The faculty must seek to remain relevant and competitive.

A combination of methodologies can be also considered to maximise the tools of the available methodologies, lean six-sigma is often utilised as a combination however this was not explored in this study. The engineering education system considered in this study requires rapid change to bring radical change to improve the performance of the system. All the departments (i.e. Engineering Sciences) within the faculty need attention as the problems are all similar across the respective departments, therefore a combination of improvement techniques must be considered by the faculty. Control measure will be crucial to ensure that any improvement project to be undertaken by the faculty.
CHAPTER 5

Conclusion and Recommendations

Chapter 5 discusses the findings of chapter 4, and provides a conclusion and recommendations from the study investigation.

5.1 DISCUSSION

The results attained in chapter 4 indicate that the engineering education system under investigation is under strain in producing a high number of graduates. The results considered show symptoms of a system that requires improvements to achieve a higher number of graduates. The alarming sign is that there has been a constant decline in the number of graduates. Furthermore accumulatively 57.1% of students take five or more years to complete their studies. This necessitates that the system to be evaluated to find problems (variations) within the engineering education system, and establish innovative ways to resolve problems within the system. Sources of variation were not extensively examined due to lack of access to students, data was mainly utilised to evaluate the performance of the system and students were (are) likely to be out of the faculty’s database and thus no possible interviews were possible.

The improvement methods reviewed in this study, each present their respective advantages, however they all seek to improve the performance (and quality) of a system. It must be noted that ultimately all the methodologies advocate for an improvement in quality and generally a decrease in inventory within a system (or process) to ensure higher profit margins; in this case reduction of inventory and variation in the transformation process and a greater throughput to allow for higher output of graduates.

In relating the available methodologies to the engineering education system, cognisance is taken of the system in a holistic perspective and as well from a sub-system level. Each methodology presents different improvement objectives which can be linked to the education system under consideration. The engineering education system has a long lead time compared to other manufacturing processes, thus the system requires a different thought process to have rapid and radical change. The faculty must therefore maximise all the advantages of the respective improvement techniques, the different (respective) underlying
The principles of the four techniques can potentially be used at the respective levels of the system.

The education system in this case study was considered to be a three tier layered system, figure 5.1 presents the sub-system levels of the education system in this case study.

There are various stakeholders within the system, it is thus imperative that all stakeholders have an improvement initiative at their respective levels and ultimately see their contribution to the macro-operation (transformation process). This will create an environment for ownership at each specified level of the system and dedication (or determination) towards improving the system at the specified level. This in turn also means that process improvement become a culture within the organisation (or system) to enable the constant improvement for the system to improve its student throughput whilst ensuring that improvements are effected at the various levels of the system. Stakeholders at specified level will be responsible to ensure that the processes are stable at the specified level of the education level. The study proposes the implementation of the improvement techniques as depicted by figure 5.2.
The varied improvement techniques can be implemented at the respective sub-systems; the most suitable technique for the respective subsystem would be selected for implementation.

Figure 4.3 demonstrated a modified engineering education model that included a feedback loop as a key feature for any improvement process initiative to be undertaken by the faculty, further to this; the systems must have an effective communication system amongst the sub-systems and associated stakeholders to ensure that any improvement at any specified level complements the overall objective of the system improvement drive, the communication must seek to eliminate any possible frictions between stakeholders at the various levels of the education system. This will entail that roles and responsibilities are well detailed and shared with all stakeholders, understudying of each stakeholder’s role ensures no duplication of work and synergy is maintained at all times.

Theory of constraints would best be applied to the engineering education system at the HOS level, mainly focusing in identifying bottlenecks within the system and ensuring that proper resources are deployed to relieve constraints in the system. This might entail appointing good lecturers, and developing additional educational resources in improving the throughput rate of the system. Constraints identified in the first and second year will need intervention at a high level of leadership as they are a mixture of modules offered by the Faculty of Engineering and Built Environment, and the Faculty of Natural Sciences. This will necessitate cooperation between the two faculties and a review of policies in placed hence the need for senior leadership to lead this process and eliminate the constraint(s) identified.

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<table>
<thead>
<tr>
<th>System Level</th>
<th>Methodology To Be Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOS</td>
<td>TOC</td>
</tr>
<tr>
<td>HOD</td>
<td>Lean and Six sigma</td>
</tr>
<tr>
<td>Lecturer</td>
<td>SPC and Six Sigma</td>
</tr>
</tbody>
</table>

**Figure 5.2: Subsystem Suitable Improvement Methodologies**
The HOD sub-system level, requires the flow of students to be improved and this would best be achieved through the implementation of lean techniques (or a combination of lean-six-sigma), the aim is to better manage available resources and improve flow around constraints which would have been identified at the HOS level (i.e. subjects with high failures). The department(s) must seek to identify the sources of variation affecting student retention and the throughput from the respective departments in the faculty.

To enable a better flow of students (or progression of “WIP” in the transformation process) pre-requisites need to be re-evaluated to find alternatives to reduce the bottlenecks, a mentorship programme should be considered to aid student throughout their entire duration of enrolment in the faculty. More interactive tutoring session should be established, students often do not participate in activities unless they contribute to their final semester score. This culture would need to be changed to allow for more interaction and engagement between students and lecturers; these changes however will require a financial investment to effectively implement them. The quality of teaching must also be evaluated by HODs as the blame cannot solely lay with the students.

SPC and Six-sigma are best suited to be implemented at a lecturer sub-system level; the subjects (or modules) are micro-operations within the transformation process. All resources need to be effectively utilised at bottlenecks (i.e. subjects) identified, this may require additional support for lecturers that teach the constraints. Sharing of knowledge and best practices must be extensively entrenched as a culture at the lecturer sub-system level to allow the lectures to share experiences as they at some point teach the same students. The system needs to be innovative in its approach to interacting with students and should be able to utilise social networks and other forms of the media as an added tool for lectures to engage with students. Access to these added utilities will require monitoring to measure how often students access these added tools, if students do not fully utilise the additional learning tools, then it does not make financial sense to spend money on a service not adequately utilised to maximise the students ability to perform well. Additional to the media utilities, students must be profiled to determine areas of strength and weakness. Since the lectures often interact with students more than the other stakeholders in the education system dashboard must be developed by lecturers for the students to access and evaluate their progress in the respective subjects. Struggling students must be placed on a programme to aid them keep up with their studies and ensure that they are successful in their studies.
More group projects will aid students to develop team work skills; however this must be closely monitored to evaluate that it is beneficial to all students, mentors must also be involved in the group projects to provide guidance to students.

Feedback from students is a vital ingredient to measure that subjects are delivered in a comprehensive and efficient manner; this can be accomplished through teaching evaluations which will also aid the lecturer in ensuring that students fully comprehend all that is being thought and improve the manner in which lecturers disseminate information to the students. This will further create more interaction between students and lecturers, as they will be able to comment on the how the respective subjects are being delivered and how they can be improved (or altered). More interventions are needed to monitor the progress and performance of students rather than mainly relying on formal assessments; e.g. students can be divided into groups and prepare presentations based on lectures already delivered.
5.2 CONCLUSION

In chapter one, the problem statement and objectives (aims) for the investigation were presented. The aim of the investigation was to establish if continuous process improvement methodologies can be applied to an engineering education system. In order to assess the applicability of any improvement four process improvement techniques were discussed in the literature review presented in chapter 2. The performance of the engineering education system was evaluated to establish the performance baseline for the system under consideration in this study. The engineering education system plays a crucial rule in aiding the government to accomplish all infrastructure development projects so as to allow the country’s economy to grow by making certain that the necessary skills needed for all the country’s aspirations can be achieved by producing the required number of engineers per million citizens. According to the Human Sciences Research Council, the ratio of engineers per million citizens in South Africa is 473, whereas other developing countries such as Chile and Malaysia have a ratio of 1 460 and 1 843 respectively. It is therefore evident that changes need to be made to improve the number of engineers produced by the engineering education system.

It was noted from table 4.1 that subjects linked to non-graduating student were mainly in the first year and second year of study in the engineering education system. These subjects (modules) are a variety of subjects offered by the Faculty of Engineering and Built Environment, and Natural Sciences Faculty. The first year failures put a strain on the system in terms of “raw material” being charged into the transformation process. The engineering education system cannot do much in rectifying the raw material coming into the transformation process, as students are enrolled into the faculty based on their high school results and meeting the requirements set by the faculty (or university). The second year subjects have been identified as the constraint in the education system for this investigation. This necessitates that more effort be spent identifying struggling students at an early stage (i.e. 1st or 2nd year) of the transformation process.

A closer relationship with the Student Services Centre is required to aid struggling students to find alternative studies to pursue in their university career if their aptitude will not yield success in the engineering education system. However this holds a conundrum for the engineering faculty as student retention was identified as a key contributing factor in producing a high number of engineers. Profiling students with the aid of the Student Services
Centre can yield great success and enables the faculty to maximise the available resources at the university.

The performance of lecturers needs to be monitored to ensure they can effectively teach and convey all the learning material to students, and review that all students fully comprehend what is being thought to them. This warrants that regular feedback to be given by students on the performance of lecturers and the study material offered, this will aid in identifying opportunities to improve the quality of teaching and ensuring that the courses offered (or delivered) is responsive to the expectation of both the student and lecturers (and admin staff) at all times. Social networks need to be utilised to provide extra support to the students, it is noted that there is a resource called Edulink is currently utilised by the faculty to post tutorials and other artefacts to maximise the students access to learning material and resources. Trending the students’ access to Edulink will enable the faculty to have a picture of how their students utilise this facility. Input from the students must be sourced to ascertain the effectiveness of this tool, alternatively a “SharePoint” facility can be implemented that will allow students to exchange ideas and notes pertaining to their studies. It is imperative that students must be given the opportunity to share ideas related to their studies.

The performance results presented in section 4.1 and 4.2, illustrated a decline in the number of graduates produced by the engineering education system under investigation. Factors governing the decline were not extremely examined in this study as it was beyond the scope of the investigation. However it was evident that students failing (or repeating subjects) and dropouts (voluntary and academic exclusions) played a key role in the engineering education system’s progress decline in performance. Students repeating subjects affects the system’s capacity in taking in more students into the engineering degree programme and furthermore this affects the system’s ability for potential income from the Department of Higher Education.

There can be a variety of reasons to why the system is failing beyond those that have been identified as key factors, however it is noted that all systems are designed to perform a certain function; the engineering education system’s primary objective is to produce quality graduates and contribute to the advancement of mankind in developing technologies beneficial to society, as well as to add on existing body knowledge within the engineering fraternity. However the definition of quality in this regard has not been well defined with regards to the education system under investigation, thus a definition of quality must be attained to effectively implement improvement techniques and provide a tangible measure for quality in relation to the engineering education system. A more tangible measure will aid
the stakeholders to better establish (and implement) quality control plans (QCPs) and Inspection and Test Plans (ITPs) similar to those utilised in manufacturing processes that provide interventions at all key points of the production line. Tangible goals (and measures) will provide the stakeholders (i.e. admin stuff, senior management, lecturers and students) to better manage the progress of material (i.e. students) in the transformation by having more intervention rather than only relying on test and exam results which do not provide details as to where the variation started to occur.

Datebooks are used in the manufacturing of products and provide a historic picture of the product manufactured and enables the ability to trace how the material progressed prior to being a complete product, it further provides intervention for customers to review how well the product complies to the desired specification set out by the customer, currently the engineering education system does not provide this ability in its transformation process.

The literature review focused on four improvement methodologies, namely the following:

1. Theory Of Constraints (TOC)
2. Lean
3. Statistical Process Control (SPC)
4. Six-Sigma,

Each of the above mentioned methodologies postulates its own advantages; these advantages need to be exploited to benefit the entire education system. Elevating the system to a new operating level requires an increase its pass rate (throughput) and a decrease in the duration students (WIP) spend in the transformation process, however this will require all stakeholders to be geared up and willing to change things around, and have a more dynamic engineering education system that is responsive to its student’s needs and industry requirements.

The improvement methodologies considered have the ability to progressively transform the education system if they are appropriately applied at the different spheres of the system, it must be noted that prior to initiating any improvement project there must be a “buy-in” (or commitment) at all levels of the engineering education system, furthermore the improvement initiative must also involve the greater university community so as to ensure that the faculty does not work in a silo separate from the university’s vision (or mission), thus any improvements to the engineering education system must relate to the learning philosophy of the university.
The investigation evaluated an engineering education system at a South African University (University of Johannesburg), the performance analysis of the system indicated that the system is not operating at its optimum performance. It is thus possible feasible to apply continuous process improvements methodologies to the system in its current state, process improvements will also be able to cure the “illnesses” within the system rather than treating the symptoms affect the output of the system.

The desired outputs of the engineering education system must be well defined to enable the process (or system) improvement initiative to address the required gaols. Quality in the system must also be well-defined to allow better control and early identification of any defects or any variation in the processes involved in the system.

The establishment of a gaol or aim for the engineering education system will allow the utilisation of the prescribed continuous process improvement methodologies to enable better management of the variance in the system, and in turn reduce the inventory of students (WIP) within the system by identifying system constraints and provide resources to alleviate (or better manage) the constraints.

The work done by Kanakana et. al at TUT utilised Lean Six Sigma to improve the output of a department within the engineering faculty, engineering education systems in South Africa are similar it is plausible that lean six sigma can yield the desired results as illustrated at TUT. However this study postulates a different thinking towards rapidly and radically improving the throughput of the engineering education system whilst also improving the student retention of the system by utilising different process improvement methodologies at the respective system levels of the engineering education system under consideration. Although no pilot project was done to verify the different thinking process postulated, new ways of thinking are required as students evolve with time and the system needs to be dynamic to care for these changes.

Furthermore in order to ensure that there are sustainable improvements to the output of the system, it is imperative that all stakeholders are involved in making certain that the system’s performance is rapidly improved. Often senior leadership of organizations set the targets to be achieved by stakeholders (i.e. lecturers and faculty stuff) at lower levels of the organization. Thus implementing change at all the levels of the organization allows the ability to have set targets to be achieved by stakeholders at specified level of the education system. The usage of the improvement methodologies at the different levels allows for those involved in the education system to have ownership of set targets to achieve within their
area of responsibility. This allows management to take the lead and actively partake in improving the throughput of the system by utilising TOC to identify the constraints and working with the lecturers utilising SPC to better manage the improvement and establish synergy at all specified levels of the faculty. Therefore it is feasible to apply continuous process improvement to the education system under consideration, applying improvement methodologies at different levels will also aid managers in the education system with their decision making and allow for appropriate allocation of resources and planning for the future to remain competitive in retaining and attracting top students to the faculty. The resultant (improved) output will ensure a long standing and beneficial relationship with the government and industry.

5.3 RECOMMENDATIONS

The recommendations of this investigation is that further research must be conducted to establish the impact of the curriculum changes in the high school education system in South Africa in relation to the readiness of students in progressing with university studies.

A better relationship with previous students (Alumni) from the engineering faculty must be established to help with mentoring students. A mentorship programme amongst students within the engineering education system must be investigated to allow students to share experiences pertaining to their university career and studies.
LIST OF REFERENCES


ANNEXURE A

Data utilised for the investigation was attained from Microsoft Excel and analysed using the same programme, this is a representation of the data utilised in the study.

The data supplied in the appendix was utilised to analyse the performance of the education system considered in this investigation. Table A.1 illustrates the performance of the respective engineering departments within the faculty; the table presents the percentage of graduates per department. The total number of graduates compared with students in enrolled in the faculty over a period of time is represented in table A.2.

A rolling year - on - year representation, comparing the number of graduates and students enrolled in the respective departments in the faculty is provided in table A.3. Table A.4 further presents the number of graduates from the faculty over a period of time. The data is broken down to into the chief contributing curriculum subjects (modules) related non-graduating students from the engineering education system in table A.5, the system was further analysed to review all subjects related to the non-graduating students in table A.6.
Table A.1 Departmental Graduates Breakdown for 2012

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- DEP OF MECH ENG SCIENCE Total: 27.07%
- DEP OF ELEC & ELEC ENG SCIENCE Total: 44.36%
- DEP OF CIVIL ENGINEER TECH Total: 2.26%
Table A.2 Students Graduating over time and students enrolled in the faculty

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Table A.4 Total comparison of graduates and students enrolled in the respective departments in the faculty

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ANNEXURE B

Annexure B provides the paper utilised at the IAMOT 2015 Conference Proceedings, the work covered in this minor dissertation was presented as part of the conference proceedings.
CONTINUOUS PROCESS IMPROVEMENT APPLIED TO AN ENGINEERING EDUCATION SYSTEM

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ABSTRACT

The Engineering education is considered to be a system. Most engineering education systems are under pressure to meet the demands set by its government and private industries. While an expensive student throughput increase is possible, continuous improvement of the education system at all levels will be a more feasible and realistic approach. Within the operation management community a multitude of process improvement champions are competing for the attation of managers (or organisation leaders). Each champion advocates the adoption of their improvement methodology. Almost all plead that if one can adopt their specific tools or follow a specific way of thinking, all operation problems can be solved. Most managers (leaders) are however still confused to select the best process improvement methodology for their situation or system’s culture. In this research study several process improvement methodologies were evaluated and related to issues in an engineering education system. The objective is to support heads of an engineering education system with strategic operation decisions to meet future demands. Working through the apparent conflicting claims of performance improvement programs, it was found to critical to concentrate on the primary and secondary effects of these programs. Although each improvement methodology can contribute valuable approaches to an engineering education system, it is still found to be a challenge for leaders to define quality education and set targets for continuous improvements. The finding of this study illustrates that the various continuous improvement process methodologies can be utilised at various levels of the engineering education system. In order to fully maximise the effectiveness of the improvement methodology or initiative the system must be transformed from the traditional engineering education system to a more innovative system which includes process improvement as part of its culture.

Key words: Process, System, Improvement, Constraints, Throughput Rate

INTRODUCTION

The dawn of the twentieth century has been greeted with great technological feats being achieved by mankind; one can argue that this can be credited to the ideas and methodologies developed during the Industrial Revolution Era. These technological accomplishments have created what is now known as the global village (or globalization) whereby companies (or organisations) no longer only
focus on local (i.e. domestic) markets but now compete for a bigger slice of the pie in international (foreign) markets in the pursuit of greater profit margins and most importantly to ensure that customer satisfaction is maintained and, or constantly improved.

An inherent trait of globalization, is that it requires organizations to be competitive in the way they “do business” by improving efficiency, reducing cost, enhancing the quality of products or service (s), and an improvement in general business processes.

Customers now have a greater range of products and services from which they can select, which means organizations need to deliver a product or service (s) of good quality at a reasonable price. To sustain a good level of customer satisfaction organizations need to be able to deliver good quality products at the promised cost, and on time to guarantee an advantage against their competitors. In order to preserve any advantage over competitors, organizations need to have continuous process improvement programs intertwined with their company objectives; this will breed a culture of improvement within the organization [1].

The purpose of any improvement process strategy/initiative is to achieve a better utilisation of all resources and reduce all waste associated with any process. Companies that survive, thrive, and grow are constantly changing and improving [1]. Process improvement entails focusing efforts in doing things in a more efficient and effective manner, rather than managing crises or “fire-fighting” issues.

Developments made during the industrial era, improved methods of manufacturing goods, management of systems and business processes within organizations. No matter the period in time, businesses have and will always seek to constantly increase profit margins. In order to achieve greater profits changes had to be made, meaning factories had to be managed more effectively and efficiently. The pioneers of the industrial era, such as Henry Ford (Ford Motor Company) utilised better manufacturing systems and processes to have the first moving assembly line, which gave Ford an advantage over its competitors and ensured business success. Ford built good quality cars at a cheaper production price and rewarded its factory workers with good wages.

Manufacturing has grown since the first assembly line, and as a by-product of the industrial era, trade has increased amongst nations. Organizations constantly look for ways to improve the way things are done to maintain and/or increase their market share.

Several improvement methodologies have been developed since the early 1990’s but most organization were wary of change, and often used staff reduction as a means of cost savings, this was however not an effective tool as it decreased employee satisfaction. Business Process Re-engineering was developed as a method to improve, redesign systems, and processes.

Methodologies such as lean, six-sigma, statistical process control and theory of constraints are the currently widely used as preferred improvement methods. Highly competitive markets require advanced methods to be utilised and necessitate a culture of continuous process improvement to be in the fibre of any organization aiming to survive in the global market.

Theory of constraints (TOC) is an improvement methodology centred on the premises that all organizations are constrained by some limiting factor, hence the growth of all organizations is restricted, and they do not grow as large and rapidly as preferred by the organization’s leadership.
The constraint limits the profit margins of a company or the output of system, otherwise organizations (or systems) would achieve infinite profits or products [2, 3].

The TOC approach is defined into a five step approach, namely the following:

- Identify the constraint.
- Decide how to utilize the constraint.
- Subordinate everything else and focus on fully utilizing the constraint to the fullest extent.
- Evaluate the constraint to ensure improved productivity.
- Repeat the above steps by finding a new constraint to manage/improve [2, 3].

All organizations desire to maximize profits from all activities they are engaged in; however this requires integration of engineering design, material, and control strategies to ensure quality products are delivered to customers. Quality products require minimal variation in product process output. Six-Sigma (66), advocates the elimination of quality defects within a production process and business processes.

Sigma (6) is a manufacturing process term, which is defined as a percentage of defect-free products from a production process. A six-sigma process, is a process that produces 3.4 defects per million, thus 99.99966% products manufactured are free of defects. Six-Sigma represents the capability of a core business process, measured in defect per million opportunities [8]. Six-sigma must be applied holistically within an organization starting from raw materials through to finished goods (or products).

Analytical tools used in Six Sigma have been used in traditional improvement programs for many years. However their application in Six Sigma is an integration of the tools throughout the entire organization's management system. Tools utilised include the following:

- Flow charts
- Run charts
- Pareto charts (diagrams)
- Check sheets
- Cause and effect diagrams, and
- Control charts

Statistical process control (SPC), is a process improvement methodology utilised for monitoring, managing, maintaining and improve process performance through the use of statistical methods. SPC effectively reduces product recalls, reworks, scrap rate, warranty costs, and improve customer satisfaction, increase market share, profit margins and productivity.

SPC utilises control charts (similar to those utilised in six-sigma) to determine when a process is going out of statistical control and adjust it before it diverges out of the statistical limit. However the control charts do not present a clear picture as to what is erroneous within the process, it is therefore important that an appropriate measuring system be in place. Required data to be
measured include process output quality, quality costs, process performance, etc. These lead directly to statistics, statistical methods can be applied to provide, (1) process behaviour through assessing quality levels of the process; (2) portray information as to when it is necessary to identify process variations and when not to look for them; (3) information where variation is likely to occur; and (4) understanding of the operation of the system to aid in making process or product improvements.

The statistical results must be interpreted such that they can provide useful information on how to achieve quality products by appropriately adjusting the process where it is deemed necessary.

The objective of any organizations offering a product or service(s) is to eventually become a lean organization. Lean organizations are characterised by the minimal waste associated with their systems and processes. Lean organizations endeavour to reduce (or eliminate) waste on a continuous basis, which reduces costs and can be translated into higher productivity and market share. Any continuous process improvements must always satisfy all customer needs.

System improvement can be accomplished in measuring three operational measurement parameters of a system, namely the following:

- **Throughput**

  Throughput is the rate at which money is generated by the system through sales.

- **Inventory**

  Inventory is all the money that the system has invested in purchasing things it intends to sell.

- **Operating expenses**

  Operating expenses is money that the system spends to turn inventory into throughput [16].

The improvement of the above mentioned operational parameters will lead to financial gains in the organization, as that is the main aim of any system improvement.

In preparing to implement any process improvement the capability and capacity of the system must be established prior to implementation. Capability is the organizations ability to produce the desired product as per customer requirements, a capability index (Cpk) is utilised to ascertain how well parts are being produced to fit within the specified range of the design limits [16]. Process capacity must also be evaluated in conjunction with the capability of the system; capacity will ensure that the system has the ability to meet the demand placed upon it.

The aim of this paper is to evaluate current available methodologies and ascertain the viability of utilising one (or all) of the techniques in the study presented in this paper.

The case study will be based on an Engineering Education considered as a system. A majority of engineering educations systems are under pressure to meet the demand set by its government. An expensive student throughput increase is possible; however continuous improvement of the education system at all levels will be more feasible and realistic. Several process improvement methodologies will be evaluated and related to issues in an engineering education system.

The paper further seeks to aid managers of an engineering education system with strategic operational decisions to meet future demand.
METHODOLOGY

The purpose of the research is to identify and discuss process improvement methodologies, and ascertain if the methodologies can be applied to an education system.

The research undertaken in this investigation is qualitative in nature, and aims to test the possibility of applying process improvement methodologies to an Engineering Education system. This approach provides an “applied” approach to the study and has been considered best suited for the investigation, as it will enable the possibility of applying existing knowledge to the proposed investigation.

The research also contains elements of being theoretical in nature, as it bases some of its premises on the works of other researchers, and explores continuous process improvement strategies which can be utilised in an education system.

The investigation involved a literature review and utilised an Engineering Faculty’s student performance (final results) as the premises to evaluate the performance of the system. The constraints experienced during the investigation were the following:

- Readily available data to analyse the Education system.
- Definition of quality in terms of an engineering education system.
- No prescribed outputs (results) from an engineering education system.
- No desired continuous improvement targets.

Data Collection and Analysis

Data utilised in this investigation was attained from the Faculty of Engineering and the Built Environment, at a South African University. The data contains academic performance of students enrolled at the faculty from the year 2001 to 2012.

The data analysis was done on the entire data to mitigate any possible biasness on the part of the researcher and to ensure proper representation of the data is portrayed.

Random sampling was also utilised to illustrate improvement methodologies in relation to the investigation undertaken in this study. The analysis seeks to answer the following questions:

- What is the worst performing engineering discipline?
- Which subject(s) has the biggest number failures (%) or which year has the most failures?
- What is the average duration (years) a student takes to graduate?
- Can we link students that do not graduate to subjects failed?
- Is there a decline in the number of students graduating?

The results of the data analysis were modelled utilising Microsoft Excel-2010, the graphs generated provided a holistic picture of the performance of the entire education system under investigation.

The continuous improvement methodologies were applied to the data available to aim ascertain their feasibility in relation to the system under investigation. Figure 2.1 describes the approach used for the study.
FINDINGS

Education System Performance Overview

The survival of an education system relies on attracting prospective students and ensuring a high output of students graduating from the system. It is noted that no system exists without any fault, thus the system input does not always correspond to the output of the system hence it cannot be regarded as functioning at its optimum level. Processes within the system need to be constantly evaluated and improved to eliminate any waste or abnormality associated with the performance of the system or process.

Similar to manufacturing operations, an engineering education system can be modelled as a transformation process, which can be modified to incorporate continuous improvement as a key element of the transformation model.
The transformation process enables managers with the ability to direct, and control processes that convert inputs (resources) into a desired output (product or services); this is accomplished by adding value to the input(s) through the transformation process.

The overall transformation process can be viewed as a macro operation, containing micro operations within the process.

To improve the education system under investigation the transformation process needs to be altered to inherently incorporate improvement methodologies as part of its transformation process.

A transformation model incorporating continuous must be developed and utilised by an engineering education system to improve the system output. To further assist in attaining improved results, the appropriate methodology from the vast techniques available must be selected for a specific improvement goal. This is depicted as an input into the transformation process to aid in accomplishing the desired output; that is a lean or a six sigma (66) system or even a combination of both (i.e. lean 66).

The feedback loop provides information on the performance of the system, and thus functions as a control tool to adjust the inputs and transformation process to achieve the anticipated output.
The system analysis indicates a constant decline in the number of graduates being produced by the system. This is shown by the number of graduates produced from the system.

Despite the increase in student admissions to the faculty, the graduating (output) rate decreases immensely over time. The graduating rate takes note of the faculty as a whole; however, it is also necessary to further break down the results into departmental performance, with respect to the respective disciplines within the engineering education system.

Cognisance must be taken of the progress of students through the transformation process, which is a minimum of four years; the system performance is thus evaluated over a four year rolling period focusing on the percentage of students that exit the system as graduates at the end of four years.
Figure 3.5: Departmental performance as a percentage of graduates

The number of students progressively decreases after the first year of study. The failure rate (defects within the system) indicates a steadily increase in the failure rate (i.e. drop outs/deregistration) of students, and inversely it is apparent that there is a decrease in the number of graduates being produced by the system, therefore system is under constraint in delivering graduates from the transformation process and it is apparent that the system is not functioning at its optimum level.

Figure 3.6: Performance Histogram of the system over a four year period

In addressing the failure rate, it is important to note the subjects in the curriculum that have the highest failure rate. This aids in understanding which subjects are affecting the output of the
engineering education system and enables resources to be provided to alleviate the poor performing subjects. The failures account for inventory within the system, as the students fail some prerequisite subjects they become work-in progress.

![Diagram showing failing rate per discipline over a period of five years.](image)

**Figure 3.7: Failing rate per discipline over a period of five years**

Subjects which had the highest failure were found largely to be those in the first and second year of study within the transformation process. It was found that students that complete (i.e. pass) their second of study generally tend to complete their studies.

**Theory of Constraints**

TOC is the best methodology to resolve the throughput of the system. The average duration taken by students to complete the degree indicates that system is not producing graduates within the minimum period.

![Diagram showing average duration to complete engineering degree.](image)

**Figure 3.9: Average duration to complete engineering degree.**

Although the above mentioned graph does not show a huge problem with the time taken by students to complete their studies, however in breaking down the average throughput rate to reflect
the student count in terms of degree completion, accumulatively 57.1% of students complete their studies in five years or more.

![Figure 3.10: Accumulative Time taken by most students to complete the degree](image)

In reviewing the system, the constraint(s) is identified as subjects in the second year of study, consequently the second year of study is regarded as the system constraint. The following equation is derived to compute the throughput of the system:

\[
Bottleneck \text{ Throughput}_{(yr-2)} = \text{Throughput}_{(yr)} - (\text{Failures}_{(yr-1)} + \text{Failures}_{(yr-2)} + \text{Failures}_{(yr-3)})
\]

Whereby,

- \(\text{Throughput}_{(yr)}\) = total students [i.e. 2012]
- \(\text{Failure}_{(yr-1)}\) = 4\(^{th}\) year failures [i.e. 2011]
- \(\text{Failure}_{(yr-2)}\) = 3\(^{rd}\) year failures [i.e. 2011]
- \(\text{Failure}_{(yr-3)}\) = 2\(^{nd}\) year failures [i.e. 2011]

It can be seen from the equation that the throughput of the bottleneck limits the systems throughput. Time lost by the bottleneck cannot be regained, therefore a balance must be attained to reduce the inventory (i.e. students failing) within the system whilst improving (increasing) the throughput of the system. In any manufacturing system it is ideal to pass products through the transformation process in the shortest possible time, accordingly failures in the education must be minimised enabling the system to produce a high number of graduates in the specified minimum of four years.

**Lean**

The goal of lean is to ensure a smooth flow of students through the transformation process and enable students to complete their studies within the minimum prescribed time. However reviewing the data provided, it is evident that there is a discourse in the flow of students, as some students
become inventory within the system. This will require additional resources (i.e. study materials, 
finance, etc.) for the students to repeat subjects in the following year and affects the capacity of the 
system to accommodate incoming students from other upstream processes in the transformation 
process.

The transformation process flow cannot change in terms of the various stages leading up to 
completion of the degree, however the individual processes (or subjects) can be evaluated and 
streamlined to improve the progression of students in the education system. A lean organization 
entails that all individuals are experts in their area of responsibility, and they ensure constant 
improvement to the system.

The relationship between students and their perception towards the education system must be fully 
understood, in order to fully comprehend its short comings. Lectures need to further link the 
outcomes of the respective subjects to a holistic approach to the entire degree. Pre-requisites need 
to be evaluated in an attempt to ease the flow, and reduce inventory in the transformation process. 
Tangible intervention must be established to effectively monitor the performance of student, and 
offer additional resources, or better utilisation of the available resources.

A combination of lean techniques must be considered with the Last Planner being most suitable as it 
starts off with the end in sight and puts in place relevant measures to ensure that the goals of lean 
are attained.

**Statistical Process Control**

Variable control charts are utilised in SPC, these aid in certifying that the process functions within its 
specified control limits. The charts make it is possible to attain whether a process is in-or out-of-
control and furthermore assist in controlling and monitoring process variation.

Since no statistical results were readily available, a subject (i.e. Subject “A”) from the curriculum has 
been selected as a statistical sample to illustrate the viability of SPC being utilised to managed 
variation in a process. It should be noted that a "subject" is regarded as a process in the context of the 
study. The following results were attained from the statistical analysis, it was assumed that the 
system is has a 3-sigma deviation, thus z=3. The data was considered to be normal distribution. 
Random sampling was preferred as it would identify the randomness in the variation, and if any non-
random variation occurs, and possibly rectify the variance occurring.

\[
\sigma = \frac{\sigma_{2007} + \sigma_{2008} + \sigma_{2009} + \sigma_{2010} + \sigma_{2011} + \sigma_{2012}}{6}, \therefore \sigma = 10.79
\]

\[
UCL = \bar{x} + z\sigma_x, \text{ and } LCL = \bar{x} - z\sigma_x
\]

Where,

\[
\bar{x} = \frac{58.1 + 58.4 + 50.7 + 50.2 + 49.2 + 56.4}{6}, \therefore \bar{x} = 53.67
\]

\[
\therefore UCL = 63.91 \text{ and } LCL = 43.43
\]
The control chart shows that the process (Subject A) has a lot of observations (variables) lying beyond the control limits, however a majority of the observation are within the control limit but nonetheless it is clear that the process is not in a state of control, and requires some form of rectification to ensure that the process is in a stable control.

The capability index ($C_{pk}$) aids in determining the process performance, the following results were attained:

$$C_{pk} = \left( \frac{\bar{X} - LCL}{3\sigma} \right) \text{ or } \left( \frac{UCL - \bar{X}}{3\sigma} \right)$$

$$C_{pk} = \left[ \frac{53.67 - 43.43}{3(10.79)} \right] \text{ or } \left[ \frac{63.91 - 53.67}{3(10.79)} \right] \therefore C_{pk} = 0.3163 \text{ or } 0.3163 \approx 0.32$$

The UCL and LCL are compared to determine whether the process is capable or not. The lowest ratio determines the capability of the process, however as it can be seen the ratio is identical for the UCL and LCL with a ratio of approximately 0.32. In order for a process to be capable a ration of at least 1 must be achieved, thus the process is currently not capable. Improving the capability of the system is therefore important to make certain that the system can improve its throughput rate and reduce its inventory. Improving the capability of the process entails that the process variance is reduced within the education system; this will entail that the system performs within specified system limits. The data utilised to analyse the system’s does not give a picture as to where do the variance or instability come from, further investigation would be required to properly ascertain where is the system failing and a better usage of control charts be better utilised. It is evident that SPC can be applied to processes (sub-micro operations) within the transformation process to reduce variation and ensure that the system is constantly at its optimum.
Six-Sigma

Six-Sigma (6σ) postulates an elimination of any variation in the process, utilising the statistical results obtained in SPC. The standard deviation for the process is computed as the following:

\[ \sigma = \frac{\sigma_{2007} + \sigma_{2008} + \sigma_{2009} + \sigma_{2010} + \sigma_{2011} + \sigma_{2012}}{6} \cdot \sigma = 1.7983 \approx 1.8 \]

\[ \therefore UCL = 55.37, \ and \ LCL = 51.96 \ and \ \bar{X} = 53.67 \]

The control chart illustrates that the process has a lot of variation, which needs to be eliminated and ensure process performs within the specified control limits. The cause and effect diagram can shed some light into what is causing the current variation within the process; however it should be noted that this is beyond the scope of this paper.

![Six-Sigma Control Chart for Subject “A”](image)

**Figure 3.12:** Six-Sigma Control Chart for Subject “A”

The quality requirements must be clearly defined to enable better control of the process variation and allowing the organization to perform as a six-sigma institution consistently delivering quality products (i.e. students).

**CONCLUSION**

The results considered in this paper, show symptoms of a system that requires improvements to ensure a high constant number of graduates. The alarming signal is that there has been a constant decline in the number of graduates; this necessitates that the system be re-evaluated to meet the demands from the government and industry. An improved degree orientation system to enable students to better understand the expectations and demands of the degree must be reviewed to ensure students are ready to proceed with their studies.

All methodologies discussed in this paper, each present a different objective towards improving the performance of a system. These can thus be applied respectively or as a combination of...
 methodologies at the different levels of the education system to address specific process or system variations.

It is therefore plausible to implement the available improvement techniques at different levels of the education system. There are various stakeholders within the education system, it is thus imperative that all stakeholders have an improvement initiative at their respective levels and ultimately see their contribution to the macro operation (transformation process). This necessitates an environment for ownership at the specified level of the system and dedication (or determination) towards improving the system at all levels, whilst making certain that the system remains competitive in relation to the course offering to attract prospective students into the system, and maintaining a good relationship with the government and industry.

A modified transformation model for the engineering education system incorporating a continuous improvement feedback loop as a necessary feature for any improvement process initiative must be utilised. Further to this, the sub-systems must have an effective communication between the sub-systems, and associated stakeholders to guarantee that any improvement at any specified level of the engineering education system complements the overall objective of the system improvement drive. Factors governing the decline were not explicitly examined in this paper as it was beyond the scope of the investigation.

There can be a variety of reasons to why the system is failing, however all systems are designed to perform a certain function; the engineering education system’s primary objective is to produce quality graduates and contribute to the advancement of mankind in developing technologies beneficial to society, as well as to add onto the existing body knowledge within the engineering fraternity and other spheres of academics. However the definition of quality in this regard has not been well defined with regards to the education system, thus a definition of quality must be attained to effectively implement improvement techniques to any education system.

The results were largely based on a student’s final marks for the respective subjects that form part of the curriculum offered by the engineering education system; a tool (or a measure) should be developed to track the student’s progress for all respective subjects and not only assess the students’ performance solely on formal written assessments.

Further research must be done to establish the impact of the curriculum changes in the high school education system in South Africa in relation to the readiness of students in progressing with university studies. A framework must also be developed to aid the Universities in ensuring that they are always meeting the demands specific by the government and societal needs.
REFERENCES


Mossman, A, Why isn’t the UK construction industry going lean with gusto?, Lean Construction Journal 2009 pp. 24-26 www.leanconstructionjournal.org


http://www.tangram.co.uk/images/Tool0B.gif (Accessed 25/06/2013)


ANNEXURE C

Annexure C provides the Focus Group report; the report provides a summary of discussions with 12 graduate engineers who completed degrees.

CONTINUOUS PROCESS IMPROVEMENT METHODOLOGIES APPLIED TO AN ENGINEERING EDUCATION SYSTEM
Focus Group Report
Student: Siyabonga Thamsanqa Mabizela

Summary of Project:

The student, Siyabonga Mabizela (Student No.: 920306001), held a series of focus groups in September and October 2013 involving various engineering graduates (practicing engineers) who have Engineering Degrees conferred by different South African Universities. The groups consisted of graduates who had degrees conferred between the years 2003-2012.

Through the focus groups, the student gathered information to gain an insight to how the engineering is perceived by former engineering students. The outcomes from the discussions provided insight to experiences and views related to the engineering education system.

Introduction

Siyabonga Mabizela held focus group discussions with 15 practicing engineers (graduates) in September and October 2013. The focus group was conducted as part of the student’s (i.e. S. Mabizela) minor dissertation for the fulfilment of the requirements for the degree M.Eng (Engineering Management) involvement in. Participants provided information in group discussion.

The discussion was designed to gather information from the participants (graduates) in regard to the following outcomes:

1. To understand what motivated the graduates to pursue engineering education.
2. To understand how graduates perceived the university’s effectiveness in meeting their needs

Participant Demographics

Twelve participants took part in the focus group:

- 5 women (female) and 7 men (male).
- All practicing engineers
- 2 civil engineers, 4 electrical engineers, and 6 mechanical engineers
- All participants had started their engineering studies immediately after high school
- All 10 students are using some type of financial aid.

Student Perspectives

Outcome 1: To understand what motivates students to pursue higher education

Why were the graduates (i.e. students) in University?

All participants decided to go on to university while in high school and began commenced with university studies the semester after graduating from high school. The participants offered a number of reasons for their decision to proceed with engineering studies:
To focus on academics
To pursue a career in engineering
To broaden their social circle and gain opportunities for networking
They were encouraged by parents or friends
They were encouraged by high school teachers or counsellors

The participants had specific reasons for choosing a specific university they attended:
• Cost
• Location close to home
• Family responsibilities
• Availability of specific program

Eight out of 10 of those participating indicated that their goals have changed since coming out of university because of the exposure gained whilst practicing in the industry. All the participants indicated that training programmes post their engineering studies did not provide exposure to all facets of the engineering industry and rather confined them to a specific area of specialization, this meant enrolling for post graduate studies. Six of the participants are in the process of pursuing postgraduate studies in project management due to the outlook of infrastructure projects being undertaken in South Africa, the other six of the participants opted to attended short courses and training offered by their respective employer.

Outcome 2: To understand how graduates perceived the university’s effectiveness in meeting their needs

What are graduates perceptions of the engineering education system?
In general, students were extremely positive about their experiences at university. They cited a number of the engineering education system strengths, including but not limited to the following:
• access to information
• good relations amongst students
• relationship with industry
• experienced lecturers providing real life examples
• students services to assist students with difficulties affecting their academic success
• tutors
• good lectures

All the participants agreed that the engineering education system had weaknesses, including but not limited to the following:
• poor student orientation
• no mentorship programmes
• no feedback on areas to focus on to ensure academic success
• irregular lecture times

Positive Features of the engineering education system

The one overwhelmingly positive attribute mentioned by participants is the beautiful campus and resources available to assist with academic resources.

Other positives include:
• bursaries and financial assistants
• Strong academics - “I felt motivated to perform to the best of my abilities.”
• Good professors – “In general the lecturers are very knowledgeable and they really made you interested in what they’re talking about because they know so much,” and “You can tell they want you to succeed.”
• Accommodating and caring counsellors (student advisers)

**Negative Features of the College**

• The one resounding complaint from all participants is the registration process. They strongly object to the inconvenience, long lines, confusion, and red tape associated with registering. Comments included: “Registration is a waste of time, it took the entire day. People working registration can’t find the information…and the process was manual (paper based), it should be online for the convenience of students.”

• Several participants commented that there is not enough useful information about the engineering education system available: they did not get as much information about engineering studies in South Africa as they would have liked in high school; orientation was focused on a tour and not what the engineering faculty at the respective universities had to offer; students need to ask questions rather than be told information.

  “At some high schools they have career guidance teachers available for students but that wasn’t available at my school, I think it would have helped my transition to university; it would have been a much smoother process.”

All participants noted that an engineering degree was a time-demanding degree with regards to the amount of time required to complete the modules associated with the degree. Financial assistance for most of the participants was in the form of bursaries whilst 4 of the participants indicated they had student loans which they are still paying off now, thus an incentive to aid prospective engineering students by the government is worthy of investigating.

Student input into the course offering was raised as crucial aspects that must be included as part of the education system; this would ensure that the system fulfills its mandate of the system in creating a symbiotic relationship with students. Participants stated they often attended lectures, took notes, completed assignments, wrote exams; beyond that there was no relationship with education system, they felt more should be done to have the students actively engaged. It was interesting to note that none of the participants knew or were aware of a Vision and Mission statement of their respective university (or faculty), this means the ethos of the engineering education was not properly communicated or shared with students or the was a lack of interest from students (graduates) to be invested in the culture of the engineering education.

According to one of the participants “engineering is regarded the toughest degree by the Guinness Book of World Records, 18 August 2010. It consisted of 56 exams, 130 series exams and 174 assignments within 4 years accumulating to 750 working days”

In order to be successful in engineering studies perseverance was noted as a key character trait needed by an individual studying engineering; furthermore a student assist programme should be in place as participants felt that engineering students were the social outcast at university and felt excluded in most activities done at university, they stated they did not have a “university life”. Although participants stated that it was a hard degree to complete they were glad they went through hardships whilst at varsity as it built their character and prepared them for work in the industry.
Recommended Changes

It is clear from the responses and discussions that the graduates were committed to getting an educational environment that is more customer-friendly, service-oriented, and has students' needs met. They offered several ideas about changes that they believe would make it easier for future students to learn and make it more manageable and pleasant to study. Recommended changes fall into three major categories: customer service, communication, and class offerings.

Customer Service:
- Improve and streamline registration processes. Offer online and telephone registration.

Communications:
- Make more information on programs and services available to students, potential students, and high school counsellors, in a format (and in languages) they can understand.
- Provide more outreach and detailed information about programs to high school counsellors.
- Have a better relationship with high school counsellors.
- Advertise more.
- Make information more readily available on the Internet.

Class Offerings:
- Offer a broader selection of classes and allow students to give lecturers feedback.
- Lecturers to move away from the "traditional" form of teaching.