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 attetion of managers (or organisaion leaders). Each champion advocates the adoption of thier improvement methodology. Almost all plead that if one can adopt thier 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 thier 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 fututre 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 challange 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 whcich inculdes process improvement as part of it's 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 prefered 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 (6δ), 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. 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.

Radom 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 ain ascerttheir feasibility in relation to the system under investigation. Figure 2.1 describes the approach used for the study.

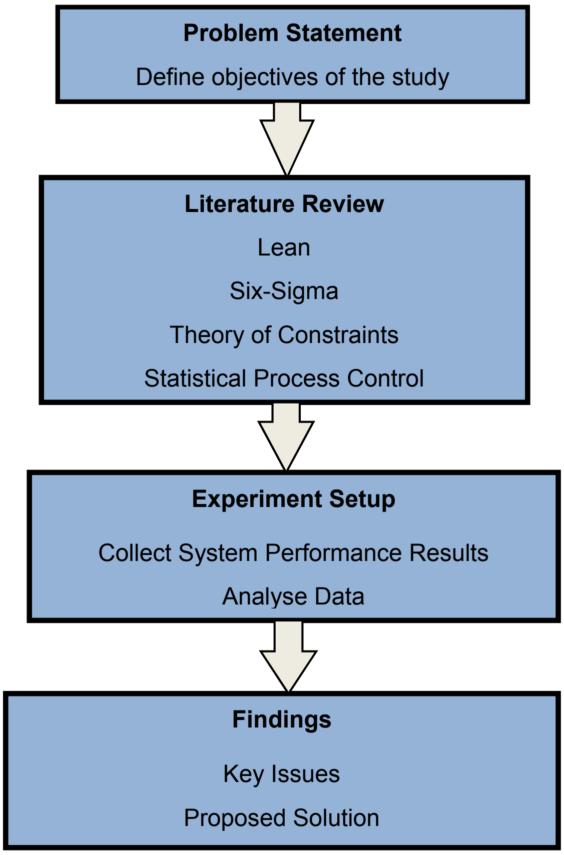

Figure 2.1: Approach utilised for the study

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.

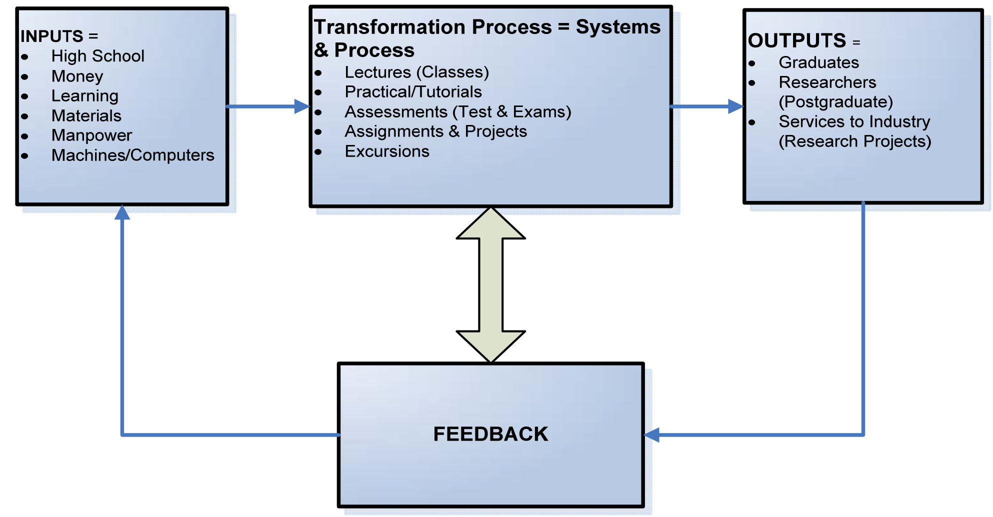

Figure 3.1: Traditional Transformation Process Model of an Education System

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.

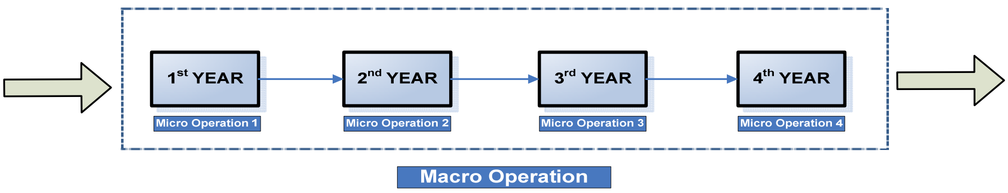

Figure 3.2: Macro and micro operation of an engineering education system

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 gaol. 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 (i.e. lean 6δ).

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.

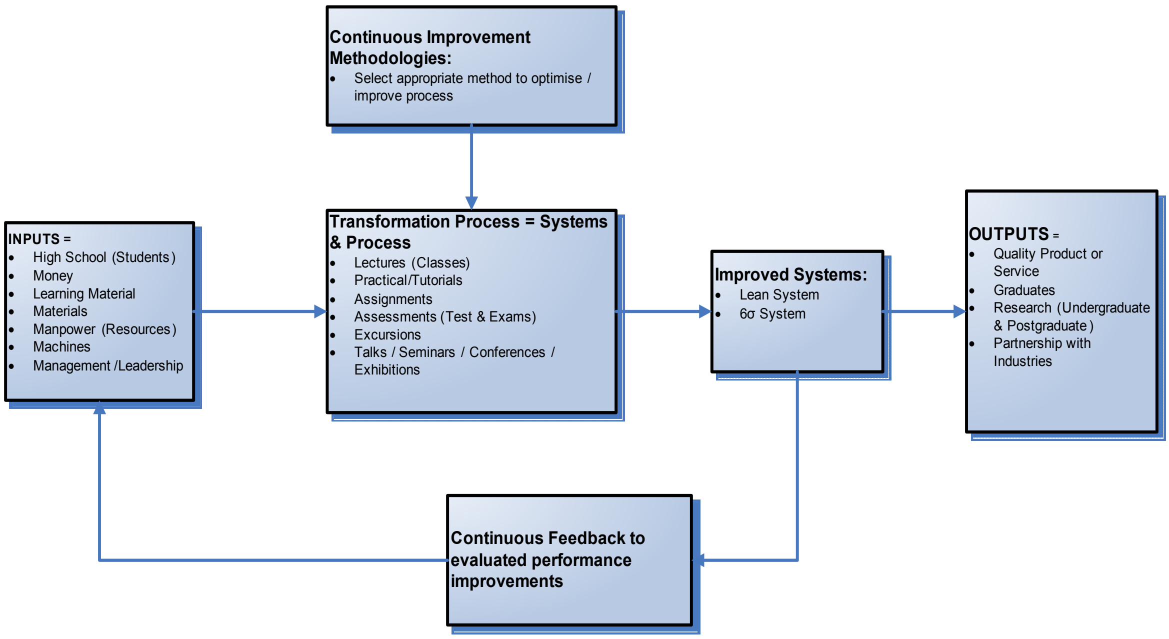

Figure 3.3 Modified Transformation Process Model of an Engineering Education System

The system analysis indicates a constant decline in the number of graduates being produced by system. This is show by the number of graduates produced from the system.

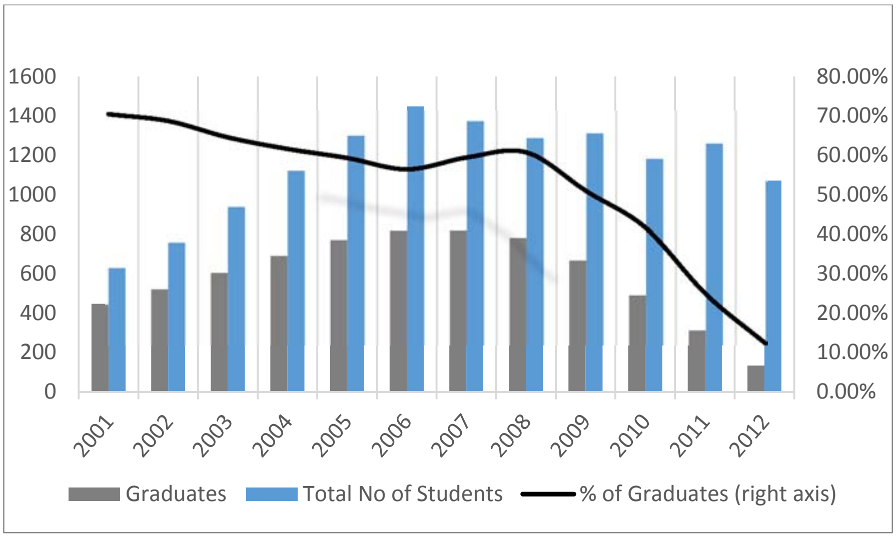

Figure 3.4: Number of graduates over time in comparison to students registered

Despite the increase in student admissions to the faculty, the graduating (output) rate decreasesg 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.

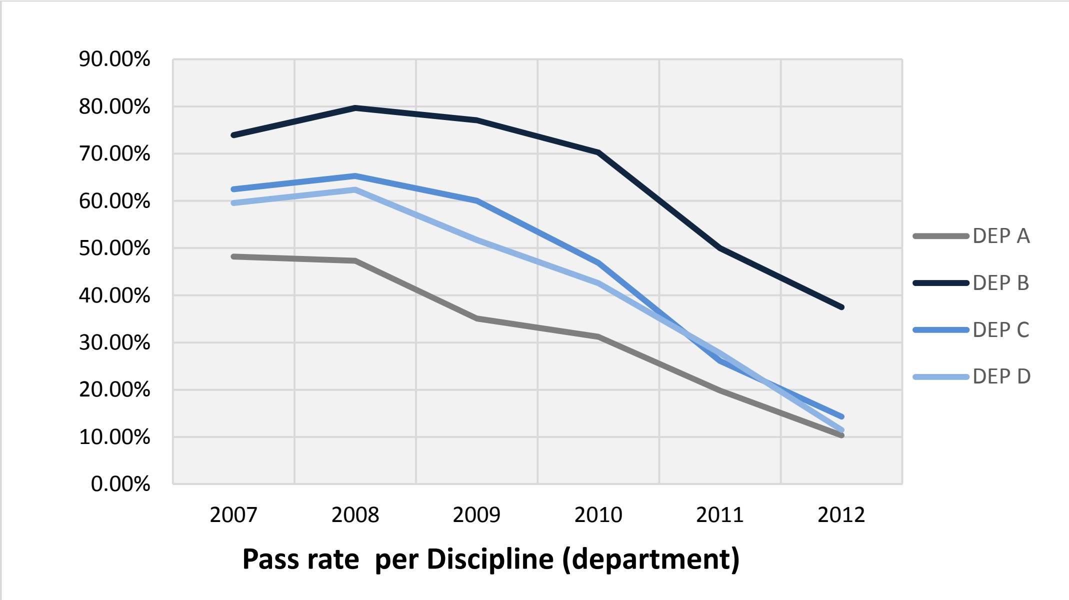

Figure 3.5: Departmental performance as a percentage of graduates

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.

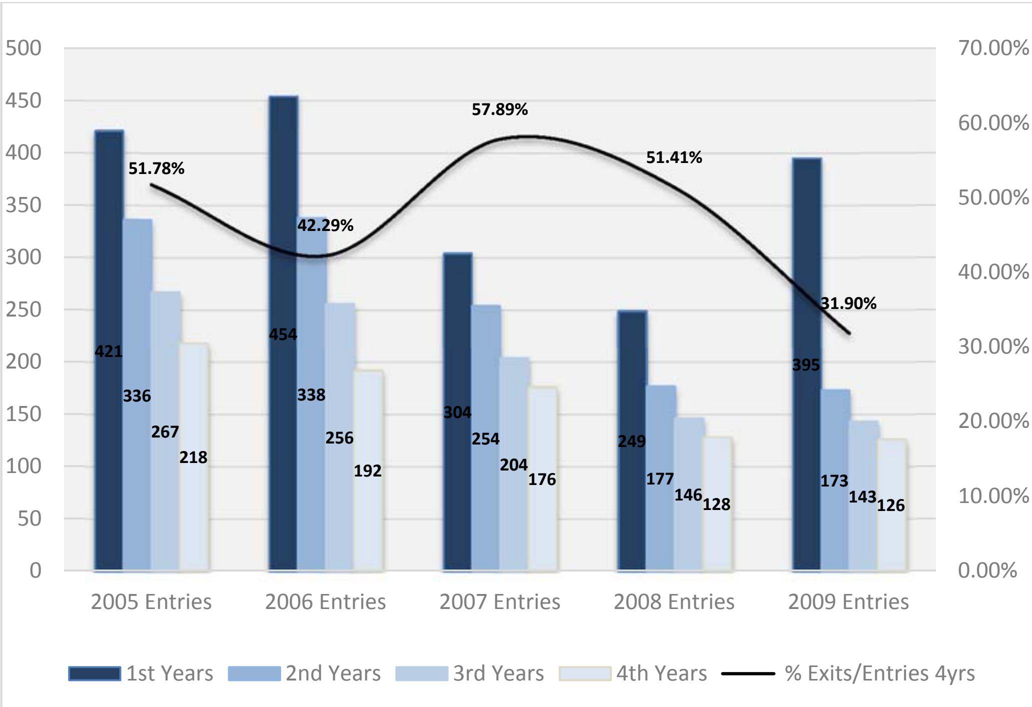

Figure 3.6: Performance Histogram of the system over a four year period

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

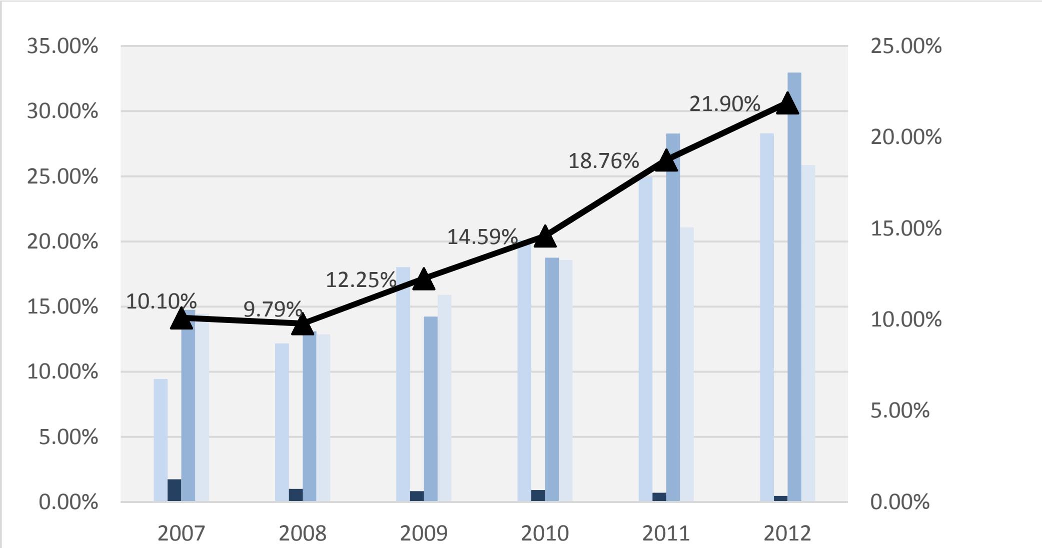

Figure 3.7: Failing rate per discipline over a period of five years

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.

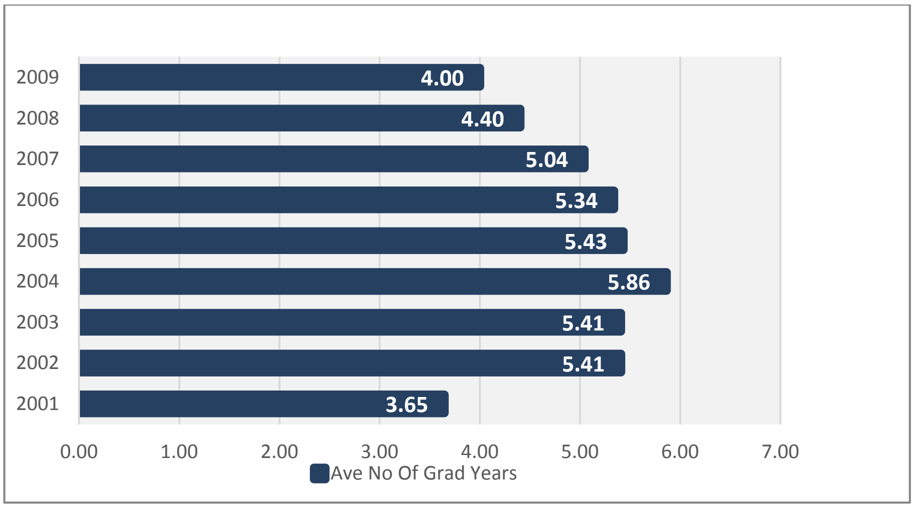

Figure 3.9: Average duration to complete engineering degree.

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.

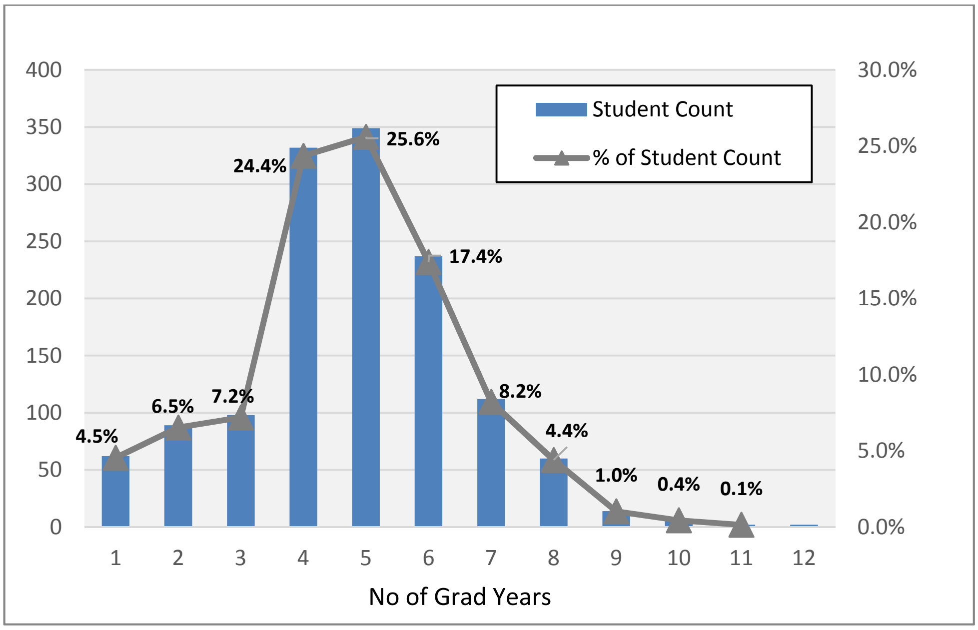

Figure 3.10: Accumulative Time taken by most students to complete the degree

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:

$$Bottleneck\ Throughput_{(yr-3)} = Throughput_{(\,yr)} - (Failures_{(yr-3)} + Failures_{(yr-2)} + Failures_{(yr-1)})$$

Whereby,

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

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

$UCL = \bar{\bar{X}} + z\sigma_x$, and $LCL = \bar{\bar{X}} - z\sigma_x$

Where,

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

$$\therefore\ UCL = 63.91\ and\ LCL = 43.43$$

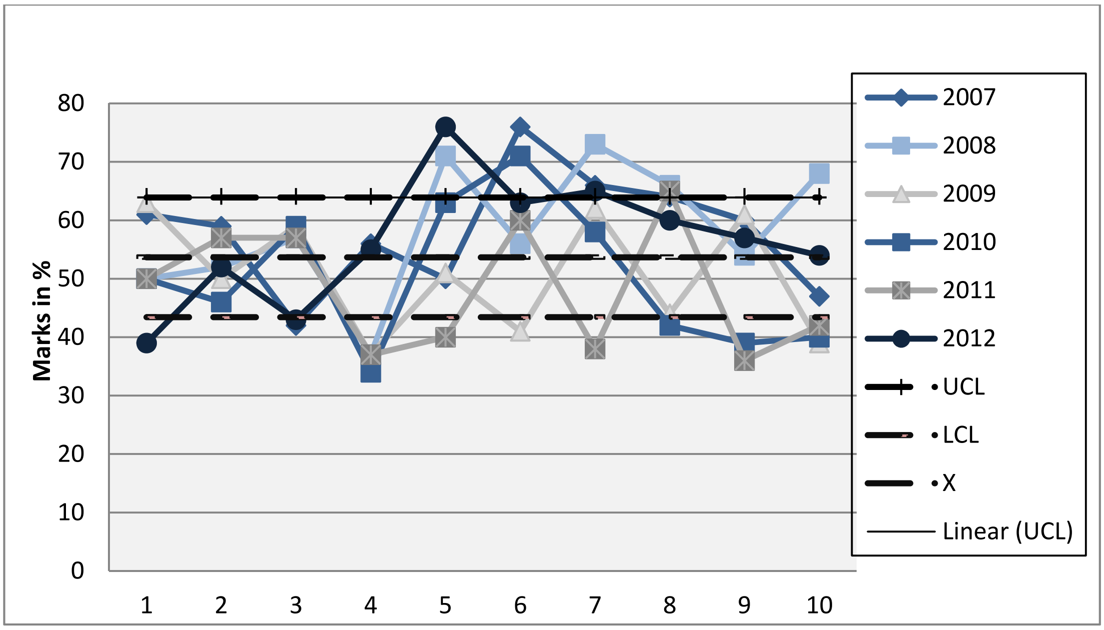

Figure 3.11: Control Chart for Subject "A"

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:

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

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

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 processto reduce variatiom 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:

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

$$\therefore UCL = 55.37, \text{ and } LCL = 51.96 \text{ and } \bar{\bar{X}} = 53.67$$

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.

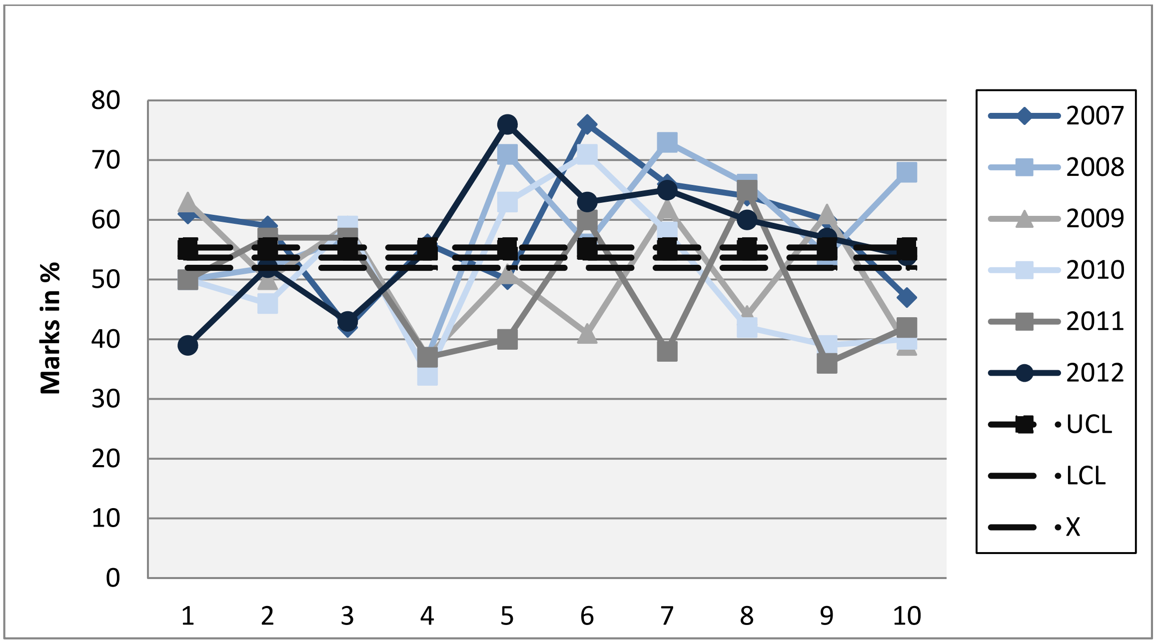

Figure 3.12: Six-Sigma Control Chart for Subject "A"

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 neccessitatesan 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.

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