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How to cite this thesis
An integrated systems approach to engineering education throughput improvement using Lean Six Sigma

by

Grace Mukondeleli Kanakana

Dissertation submitted in partial fulfilment of the requirements for the degree

D Phil

in

ENGINEERING MANAGEMENT

in the

FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT

at the

UNIVERSITY OF JOHANNESBURG

SUPERVISOR: Prof JHC Pretorius

CO-SUPERVISOR: Prof B van Wyk

NOVEMBER 2014
Abstract

Process improvement is essential for an organisation to remain competitive in the global market. Regardless of the type of products or service being rendered, such improvement is essential for remaining profitable and staying at the top of one’s industry market. The Lean Six Sigma (LSS) methodology is a preferred methodology for continuously improving business processes, thereby improving profitability and increasing market share.

Higher education institutions are increasingly being placed under pressure to improve throughput and to ensure that their institutions are sustainable. This focus on higher education inefficiencies has resulted in institutions looking for new ways to improve processes which will lead to increases in throughput.

In this study, a LSS framework has been developed and applied for improving engineering education processes. This comprehensive methodology provides a clear illustration of how engineering education processes may be improved to reduce losses experienced by higher education institutions as a result of poor throughput and how LSS may be used to improve them. Rolled Throughput Yield (RTY), network function and system dynamics, combined with statistical analysis were used to analyse and validate throughput problems and solutions in an engineering education process.

A methodology to determine where scarce resources may be channelled in order to obtain maximum impact on throughput improvement was developed and applied. The study also illustrates how LSS can be used as a unified approach by Heads of Department, Deans and faculty coordinators to make management decisions.

The research contributes to LSS process improvement methodology as it outlines how LSS is able to be applied in an educational process: tools and systems are adapted from a manufacturing context to an engineering education process context. This results in a sustainable and improved throughput rate.

Key words: Lean Six Sigma, Throughput rate and Engineering Education
Acknowledgements

Firstly I would like to give thanks to God for enabling me to finish this work. I think it is because of His grace and favour upon my life that I was able to persevere.

Secondly, I would like to thank my professors, Barend J van Wyk and Jan-Harm C Pretorius, for their support and encouragement, as well as for reading my work and providing guidance during this time.

Last, but certainly not least, my family, George, Daniel, Ndikona and the Kanakana family as a whole. Thank you for understanding and for giving me the time to finish this work. I thank you all.
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<td>Academic exclusion</td>
<td>Refers to student excluded as a result of poor academic performance</td>
</tr>
<tr>
<td>Admission points score(APS)</td>
<td>Grade points students earn per subject for a period of study</td>
</tr>
<tr>
<td>Bottleneck</td>
<td>Subjects with rolled throughput yield of less than 50%</td>
</tr>
<tr>
<td>Control plan</td>
<td>Document outlining how the process is controlled</td>
</tr>
<tr>
<td>Customer</td>
<td>The end user or a person at the next step who uses the product or service</td>
</tr>
<tr>
<td>DMAIC</td>
<td>Denotes phases in the Lean Six Sigma problem-solving methodology</td>
</tr>
<tr>
<td>Dropout rate</td>
<td>The numbers of students that cancel the course each year divided by number of students registered for that particular year</td>
</tr>
<tr>
<td>Engineering education process</td>
<td>Refers to activities which occur from when students register for a course to when they graduate</td>
</tr>
<tr>
<td>Financial exclusion</td>
<td>Students excluded as a result of not being able to pay tuition fees</td>
</tr>
<tr>
<td>Grade point average (GPA)</td>
<td>The number of grade points students earn in a given period of time divided by the total number of credits taken in that period</td>
</tr>
<tr>
<td>Lean manufacturing</td>
<td>Philosophy and tools used to eliminate waste in the process</td>
</tr>
<tr>
<td>Lean Six Sigma</td>
<td>Combination of lean manufacturing and Six Sigma techniques to improve process performance</td>
</tr>
<tr>
<td>Mean</td>
<td>The average of the data set</td>
</tr>
<tr>
<td>Median</td>
<td>The number in the middle of data sets if the data number consist of odd numbers or two middle numbers divided by two if data set has even numbers</td>
</tr>
<tr>
<td>Minitab</td>
<td>Statistical software specially designed for Six Sigma data analysis</td>
</tr>
<tr>
<td>Mode</td>
<td>The number that appears most frequently on the data</td>
</tr>
<tr>
<td>myTUTor</td>
<td>TUT student online systems used by lecturers to communicate with students regarding academic matters</td>
</tr>
<tr>
<td>Pareto analysis</td>
<td>Graphs which use the 20:80 principle in grouping variables for the purpose of indicating a few variables which have high impact on the output</td>
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<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>Pass rate</td>
<td>Students who passed, divided by students registered</td>
</tr>
<tr>
<td>Primary metric</td>
<td>This metric is a quantified measure of the defect or primary issue of the project</td>
</tr>
<tr>
<td>Process map</td>
<td>Is a map used to illustrate the relationships and flow of activities within a process</td>
</tr>
<tr>
<td>Process</td>
<td>Series of interrelated activities that transforms input into output</td>
</tr>
<tr>
<td>Programme structure</td>
<td>Refers to how the subjects are structured within the course or programme</td>
</tr>
<tr>
<td>Project charter</td>
<td>A document which contains a summary of key project information</td>
</tr>
<tr>
<td>Rolled throughput yield</td>
<td>Number of students passing subject at first attempt, divided by number of students enrolled for that subject</td>
</tr>
<tr>
<td>Secondary metric</td>
<td>Metric used to measure potential changes that may occur as a result of making changes to the primary metric</td>
</tr>
<tr>
<td>Sensitivity analysis</td>
<td>An analysis which is performed by adjusting variables in a model to determine possible outputs</td>
</tr>
<tr>
<td>SERQUAL</td>
<td>Tool used to assess service quality</td>
</tr>
<tr>
<td>Sigma level</td>
<td>Universal metric which measures process performance</td>
</tr>
<tr>
<td>Sigma</td>
<td>Referred to as standard deviation, measuring number of standard deviations from the mean to the specification limit</td>
</tr>
<tr>
<td>Simulation</td>
<td>Technique used to test more conditions than that which is practically possible, using computer software</td>
</tr>
<tr>
<td>SIPOC</td>
<td>Process map which outlines process requirements from suppliers to customers</td>
</tr>
<tr>
<td>Six Sigma</td>
<td>Systematic problem-solving methodology used to improve organisational effectiveness</td>
</tr>
<tr>
<td>SMED</td>
<td>A technique used to change dies quicker in order to reduce down time</td>
</tr>
<tr>
<td>SPSS</td>
<td>A software package used for statistical analysis</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>The average deviation of data from the mean to a point of inflection</td>
</tr>
<tr>
<td>Stella</td>
<td>Dynamics system modelling designed to incorporate both continuous and discrete variables</td>
</tr>
<tr>
<td>System dynamics</td>
<td>The approach to understanding the behaviour of complex systems over a long period of time</td>
</tr>
<tr>
<td>Throughput rate</td>
<td>Cohort analysis of number of students graduated divided by number of students enrolled</td>
</tr>
<tr>
<td>TRIZ</td>
<td>Creative problem-solving methodology</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<tr>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Variance</td>
<td>Individual deviation of the data from the mean to a point of inflection</td>
</tr>
<tr>
<td>Vensim</td>
<td>System dynamics software design to model variables using feedback loop graphs</td>
</tr>
<tr>
<td>Voluntary dropout</td>
<td>Students that drop out due to causes other than academic or financial exclusion</td>
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<tr>
<td>APS</td>
<td>Academic Potential Score</td>
</tr>
<tr>
<td>AR</td>
<td>Assistant Registrar: Student Administration</td>
</tr>
<tr>
<td>AQS</td>
<td>Academic Qualification System</td>
</tr>
<tr>
<td>CESM</td>
<td>Classification of Educational Subject Matter</td>
</tr>
<tr>
<td>CHE</td>
<td>Council on Higher Education</td>
</tr>
<tr>
<td>CTC</td>
<td>Critical to Cost</td>
</tr>
<tr>
<td>CTD</td>
<td>Critical to Delivery</td>
</tr>
<tr>
<td>CTQ</td>
<td>Critical to Quality</td>
</tr>
<tr>
<td>CUP</td>
<td>Committee of University Principals</td>
</tr>
<tr>
<td>D</td>
<td>Defects</td>
</tr>
<tr>
<td>DHET</td>
<td>Department of Higher Education and Training</td>
</tr>
<tr>
<td>DMAIC</td>
<td>Define, Measure, Analyse, Improve and Control</td>
</tr>
<tr>
<td>DOE</td>
<td>Design of Experiment</td>
</tr>
<tr>
<td>DPMO</td>
<td>Defects per Million Opportunities</td>
</tr>
<tr>
<td>DPU</td>
<td>Defect per Unit</td>
</tr>
<tr>
<td>FAEAC</td>
<td>Faculty Academic Exclusion Appeals Committee</td>
</tr>
<tr>
<td>FoEBE</td>
<td>Faculty of Engineering and the Built Environment</td>
</tr>
<tr>
<td>FTE</td>
<td>Full Time Equivalent</td>
</tr>
<tr>
<td>Gage R&amp;R</td>
<td>Gage Reproducibility and Repeatability</td>
</tr>
<tr>
<td>GPA</td>
<td>Grade Point Average</td>
</tr>
<tr>
<td>HEDA</td>
<td>Higher Education Data Analysis</td>
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<td>HEIs</td>
<td>Higher Education Institutions</td>
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<td>HEQC</td>
<td>Higher Education Quality Committee</td>
</tr>
<tr>
<td>HoD</td>
<td>Head of Academic Department</td>
</tr>
<tr>
<td>IFG</td>
<td>Institutional Factor Grants</td>
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<tr>
<td>ITS</td>
<td>Integrated Tertiary Software</td>
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<tr>
<td>LSS</td>
<td>Lean Six Sigma</td>
</tr>
<tr>
<td>MIS</td>
<td>Management Information System</td>
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<td>MSA</td>
<td>Measurement System Analysis</td>
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<tr>
<td>QPU</td>
<td>Quality Promotion Unit</td>
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<tr>
<td>ROG</td>
<td>Research Output Grant</td>
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<tr>
<td>RTY</td>
<td>Rolled Throughput Yield</td>
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<td>Abbreviation</td>
<td>Explanation</td>
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<td>Semester 3</td>
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<td>S4</td>
<td>Semester 4</td>
</tr>
<tr>
<td>SA</td>
<td>South Africa</td>
</tr>
<tr>
<td>SIPOC</td>
<td>Supplier Input Process Output Customer</td>
</tr>
<tr>
<td>SMED</td>
<td>Single Minute Exchange of Die</td>
</tr>
<tr>
<td>SSA</td>
<td>Student Services Administrator</td>
</tr>
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<td>SPSS</td>
<td>Statistical Product and Service Solutions</td>
</tr>
<tr>
<td>SRC</td>
<td>Student Representative Council</td>
</tr>
<tr>
<td>TIG</td>
<td>Teaching Input Grant</td>
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<td>Teaching Input Unit</td>
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<td>Teaching Output Grant</td>
</tr>
<tr>
<td>TOU</td>
<td>Teaching Output Unit</td>
</tr>
<tr>
<td>TUT</td>
<td>Tshwane University of Technology</td>
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<tr>
<td>U</td>
<td>Units</td>
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<tr>
<td>UoT</td>
<td>University of Technology</td>
</tr>
<tr>
<td>UoTs</td>
<td>Universities of Technology</td>
</tr>
<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
<tr>
<td>WIL</td>
<td>Work Integrated Learning</td>
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Chapter 1: Project Overview

1.1 Introduction

The revised Higher Education Act of 1997 set the scene to redesign the demography of higher education (Andrew, 2005). This resulted in the development of the National Plan for Higher Education in South Africa and served as a framework for the transformation and reconciliation of higher education institutions. Andrew (2005) noted that the key objectives of the South African National Plan for Higher Education were to increase access, equity, diversity, research capacity and reorganise the institutional landscape.

To achieve the objectives of the National Plan for Higher Education of 2001, 36 higher education institutions were merged into 23. In general, institutions which were previously disadvantaged were merged with institutions which were previously advantaged (Andrew, 2005). The merger resulted in the formation of Universities of Technology (UoTs) in 2004. Five Universities of Technology were formed: Tshwane University of Technology (TUT), Durban University of Technology, Cape Peninsula University of Technology, Vaal University of Technology and Central University of Technology.

According to Roodt and du Toit (2009), South Africa (SA) has a ratio of 473 engineers per million citizens, which is far less than other developing countries such as Chile (1460) and Malaysia (1843), and that the ideal ratio is to have 2 technologists, 4 technicians and 16 artisans for every engineer. According to the general secretary of the South African Institute of Measurement and Control, the situation for technologists and technicians is not desirable. Roodt and du Toit (2009) stated that for developed countries the ideal ratio for engineers, technologist, technicians and artisans is 1:2:4:16. For South Africa, the situation is different. The Engineering Council of South Africa indicated that the ratio for engineers and technologists is approximately 1:1. The study conducted by Roodt and du Toit (2009) indicated that the ratio of engineers, technologists and technicians in South Africa is approximately 1:1:1.4. Only having 1.4 technicians for every engineer and technologist is a disturbing statistic for a developing country such as South Africa. The country is therefore not only not producing enough engineers, but also not enough technologist and technicians. Since UoTs are primarily responsible for producing technologists and technicians, it is critically important for UoTs to graduate more technologists and technicians to fill the gap currently existing in industry.
Statistics from the Organisation for Economic Co-operation and Development (OECD) countries indicate that the study duration and success rate varies considerably between countries. While higher education participation rates have risen sharply in many European countries, about 32% of tertiary students do not complete their studies (OECD, 2013). Completion rates also vary greatly between countries. In some countries like Hungary, New Zealand, Norway, Sweden and the United States of America (USA), less than 60% complete their tertiary studies, whereas countries like Denmark, Finland, France and Japan have a 75% completion rate (OECD, 2013). Hargrove and Burge (2002) noted that even in the USA, two thirds of minority groups in engineering and science programmes will not graduate on time. Higher education survival rates range from over 80% in the United Kingdom to 55% or less in Austria, France, Portugal and Turkey. In Italy, the survival rate is just 35% (OECD, 2000). In engineering education, the completion rate varies from 58% in Greece to 90% in Japan (OECD, 2006).

The national cohort analysis of engineering students at Universities of Technology (formerly known as Technikons) responsible for producing technologists and technicians from 2000 to 2004 indicates that 17% of the students graduate within a five year cycle with 14% remaining in the system as indicated in Table 1.1 (Scott et al., 2007). This is far worse than 54% of students enrolled at traditional Universities for professional degrees in engineering disciplines who graduated after five years with only 19% remaining in the system. It is clear that the country is not producing enough technicians and technologists to align to the international ratio of 1:2:4:16.

Table 1.1: National diplomas by selected Classification of Educational Subject Matter (CESM): All first-time entering students excluding Technikon SA.

<table>
<thead>
<tr>
<th>CESM</th>
<th>Graduate within five years</th>
<th>Still registered after five years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business/Management</td>
<td>33%</td>
<td>8%</td>
</tr>
<tr>
<td>Computer Science</td>
<td>34%</td>
<td>11%</td>
</tr>
<tr>
<td>Engineering</td>
<td>17%</td>
<td>14%</td>
</tr>
<tr>
<td>Social Services/Public Administration</td>
<td>29%</td>
<td>6%</td>
</tr>
</tbody>
</table>

Source: Scott et al. (2007)

An analysis of the throughput of the Faculty of Engineering and the Built Environment (FoEBE) at TUT is shown in Figure1.1 (Beer, 2009). It illustrates that the National Diploma cumulative throughput for
the faculty during the period of 2004 to 2006 is at 5%, which is very low. However, if the analysis is extended to 2009, the throughput rate is at 21%, meaning that 6 years after entering the program in 2004 only 21% of the students graduated. By comparing this to the national statistic of 17% graduating after 5 years, it can be inferred that TUT statistics is not far from the national benchmark. However, the demand for technicians and technologists indicates that what UOTs are producing is not adequate for the market, hence the need to boost the number of graduates in order to meet market demand. This claim was corroborated by Roodt and Du Toit (2009), stating that South Africa as a developing country needs to produce more engineers, technologists and technicians than first world countries due to an acute shortage of skills.

Studies conducted to investigate throughput point to factors having a multi-causal nature and are related as much to psychological, emotional and general characteristics as to the educational characteristics of students (Araque et al., 2009, Mara H and Susan G, 2004, Nariman, 2007). It is evident that there are number of reasons why throughput is low. Factors such as motivation and attitude, family pressure and demand, financial problems, peer group pressure, lack of support services, faculty interaction with students and lecture presentation styles all play important roles (Nariman, 2007, Benseman et al., 2006, Brown et al., 2005, Scott et al., 2007, Vogt, 2008).

![Faculty of Engineering and the Built Environment Throughput and Retention Data](chart.png)

**Figure 1:1** TUT’s Faculty of Engineering and Built Environment throughput and retention data
It is evident from the work of Scott et al. (2007) that throughput is a major concern for all UoTs in South Africa and that action is required in order to solve this problem. Since Higher Education Institutions (HEIs) need to address this throughput problem, ways to solve it are required. Some of the available tools such as the Lean Six Sigma (LSS) problem-solving methodology, designed to eliminate waste in commercial production processes, may also be applied to the educational processes at UoTs to increase value. LSS is a combination of Lean manufacturing and Six Sigma techniques to reduce process variation and to improve an organisation’s bottom line.

Though most commonly used in industry, the focus of this research was to investigate how the LSS methodology could be adapted and applied to the UoT educational process in order to determine focused areas for improvement, particularly in the presence of scarce resources. If engineering education and management activities are considered as “the process”, students from Grade 12 are considered as “inputs”, graduate students are regarded as “outputs” and students not meeting assessments standards as being “defects” while students dropping out of engineering education are categorised as “rejected products”, the LSS principles may be applied to increase student throughput and in a manner similar to that of many companies to reduce defects (Hargrove and Burge, 2002).

1.2 Problem statement

The main objective of this research was to develop a unified systematic approach applicable to engineering disciplines\(^1\), based on LSS methodology, to identify where scarce resources should be focused in order to obtain optimal throughput improvements.

Sub-problem 1

Develop and apply a comprehensive LSS framework to the engineering education process. This was reformulated into Research Question 1: Can a LSS framework for engineering education be developed and applied?

Sub-problem 2

Identify where scarce resources should be focused to achieve throughput improvement. This was reformulated into Research Question 2: Can this methodology be used to identify where scarce resources can be focused in order to achieve a maximum throughput increase?

\(^1\) Engineering discipline refers to engineering professionals in South Africa as defined by ECSA, these are: technicians, technologists and engineers. This study focused on technicians and technologists.
Sub-problem 3
Illustrate how LSS may be used as a unified systematic approach for throughput improvements for the engineering discipline. This was reformulated into Research Question 3: Can the LSS methodology be used as a unified systematic approach for throughput improvement in engineering disciplines?

1.3 Methodology

A detail description of the chosen methodology can be found in Chapter 3. Quantitative research was conducted using a LSS framework to find solutions to the research questions. Data was collected from a representative sample of students at TUT. On average, TUT enrols 54 000 students per annum, of which 9 500 are in the FoEBE. The sample of representative students was drawn from the students of this faculty.

LSS is data intensive and therefore institutional data is extensively used. However, interviews and electronic questionnaires were additionally used to gather information. A quantitative research approach was used for a comprehensive statistical analysis to enable the integration of large bodies of data, to make predictions about future trends and to determine when different experimental treatments have led to significantly different outcomes (Leedy and Ormrod, 2005). Minitab, a statistical software system designed to perform LSS statistical analysis efficiently, was selected to perform the statistical analysis. System dynamics modelling was used to simulate engineering education throughput in the improve phase of the LSS methodology, since experimentation is not possible in this process.

1.4 Delimitations

This investigation is limited to the examination of the National Diploma Engineering Education Process in order to identify its deficiencies and bottlenecks with the aim of improving the throughput of engineering students. The research is not focused on the psychological factors related to education and students as these have been well researched.

Only TUT students were considered for the study although the research findings can be applied in all UoTs in South Africa where there are engineering education programmes.
1.5 Main contributions

The main contributions of this study are:

I. The development of a framework to apply LSS to the engineering education process with the aim of improving throughput. This framework was introduced by Kanakana et al. (2010)

II. The presented LSS framework offers a unified systematic approach to identify problems and allocate resources accordingly. A tool has been developed to help undergraduate coordinators, department heads, academic deans and others, to utilise this uniform and systematic approach applicable to most disciplines, to identify where scarce resources should be focused to achieve optimal throughput improvements. This was presented by Kanakana et al. (2012), Kanakana et al. (2012b), Kanakana et al. (2012c)

III. This work demonstrated how LSS and System Dynamics simulation models could be used to determine the impact of adjusting critical factors affecting throughput in engineering education.

1.6 Layout of thesis

This thesis consists of 10 chapters which cover the following content:

Chapter 1 presents an introduction to the project and addresses such issues as the research problem statement, methodology and delimitations of the study.

The literature review, looking at the application of LSS and system dynamics in engineering education, are found in Chapter 2 while Chapter 3 outlines the research methodology and discusses the different phases of the implementation of the LSS.

From Chapter 4 to 8, the different phases of the LSS are applied to the problem.

- Chapter 4 outlines the define phase of LSS problem-solving methodology.
- Chapter 5 contains the LSS measure phase and how this phase may be applied to the current study.
- Chapter 6 focuses on the analyse phase identifying the source of variation in the process. Tools such as cause and effect diagrams and brainstorming sessions and other methods are used to determine the root cause(s) of the problem.
• Chapter 7 examines the improve phase where the emphasis is placed on the potential solution of the problem and feasibility analysis to determine whether the solution is suitable for the organisation. Simulation methods are additionally used to determine optimal parameters to ensure smooth implementation.

• Chapter 8 considers the control phase and focuses on ensuring that the implemented solution remains in place after the project is completed. This chapter is important for sustaining the implemented solution.

Chapter 9 covers the discussion of results encountered during the five phases of the implementation of the LSS.

A conclusion of the study, recommendations drawn from findings and suggestions for further development are presented in Chapter 10.
Chapter 2: Literature Study

2.1 Introduction

Internationally, the importance of higher education is well established. Countries which have managed to sustain high levels of economic growth with a significant improvement in the standard of living, are those which have given priority to excellence in education and training and to higher education and training in particular, as a driver of socio-economic change and development (Scott et al., 2007). The extent to which the graduate output of South Africa’s higher education sector is meeting national needs is therefore a key concern.

The data produced by the DHET in the form of national cohort studies, validate the view that HEIs are constantly faced with the challenge to increase throughput. The statistics for all university programmes using the 2000 cohort indicate that only 30% of first time entering students have graduated within five years from all institutions’ National Diploma programmes. Focusing on UoT engineering programmes, only 17% of all first time entering students have graduated within five years from a UoT(Scott et al., 2007).

The skills shortage in South Africa is linked to engineering throughput problems. As noted, South Africa has about 473 engineers per million citizens, whereas countries like Japan, Chile and Malaysia have 3 306, 1 460 and 1 843 respectively (Roodt and Du Toit, 2009). The needs of the country and the HEIs’ performance contradict each other, hence the need to look at ways in which to increase throughput. The OECD report confirms that the difference between the proportion of skilled jobs in the labour market and the proportion of people with a tertiary education indicate that most countries may benefit if more of their students graduate with a tertiary qualification (OECD, 2013). Increasing graduate numbers will require different strategies for different countries since challenges differ. One of these strategies is to look at methodologies developed in industry to improve processes and sustainability. Adopting such methodologies may well assist institutions to examine their educational processes, identify non-value adding activities and eliminate them to increase the institutional bottom line. In order to answer the research questions, a literature review was conducted on LSS to ensure a full understanding and adaptation of tools to suit engineering education processes.
As mentioned earlier, LSS is a combination of lean manufacturing principles and the Six Sigma philosophy. These methodologies have been used by industries and service organisations for years to improve customer satisfaction, which has resulted in organisations being more profitable. LSS is defined as a business strategy focused on improving the bottom line and increasing customer satisfaction. The authors of this strategy Taghizadegan, (2006) and Burge III et al., (2004) stated that HEIs in the USA investigated the utilisation of Six Sigma philosophy to improve engineering education and to increase the retention rates of minority students. Although they did not go into the details to any great extent, focusing on the Six Sigma tools only, their work did provide an impetus for higher education institutions to pursue new ways of solving retention and throughput problems. In order to answer our research questions, the literature review was conducted in the following main areas: LSS, the engineering education process, quality of higher education and factors affecting throughput.

2.2 Lean Six Sigma

In order to develop and apply the LSS framework to engineering education, an understanding of what LSS is and how it applied to manufacturing is essential. LSS is defined as relentless, sustained improvements (Taghizadegan, 2006). It is a recent approach in process improvement that combines the discipline of lean manufacturing process improvements and Six Sigma process improvements to capitalise on the advantages of each discipline (Does and De koning, 2008). The aim is to achieve total customer satisfaction as well as improved operational effectiveness and efficiency by removing waste and non-value adding activities, decreasing defects, decreasing cycle times and increasing first pass yields, all resulting in significant cost savings.

LSS has yet to be fully implemented in education processes. Nevertheless, some preliminary studies such as those outlined by Hargrove and Burge (2002) and Burge III et al., (2004), describing how higher education institutions might use Six Sigma to improve retention of engineering students, have laid a foundation, but evidence of successful implementation is lacking. The framework developed by Burge III et al., (2004), Hargrove and Burge (2002), motivated this researcher to look into implementing LSS in the education process.

Many industries have implemented LSS successfully. Does and de Koning (2008) reported on the successful implementation of LSS in financial services in their *Lean Six Sigma in Financial Services* study and stated that the implementation of LSS in three projects in insurance firms had resulted in $565 000 savings annually. Although LSS is a recent approach, it is based on successful lean manufacturing and the Six Sigma principle which form the basis of its success.
Does and de Koning (2008) said that LSS methodology contains the same steps as the traditional Six Sigma steps: Define, Measure, Analyse, Improve and Control (DMAIC). Each of the DMAIC phases is broken down into two steps. For each step, a list of deliverables is defined. The only difference between Six Sigma and LSS is that lean tools are embedded in the LSS phases as are standard improvement models. The following LSS phases are outlined by Furterer and Smelcer (2007), Does and de Koning (2008) and Allen and Laure (2006):

- Define: project definition
- Measure: define aspects critical to quality (CTQ) and validate the measurement procedure
- Analyse: diagnose the current process and identify potential influencing factors
- Improve: establish the effect of the influencing factors and design improvement actions
- Control: improve process control and close the project.

In order to unpack the LSS tools, one needs to look at each component of this methodology separately. The following sections outline the description of lean manufacturing tools and Six Sigma tools.

### 2.2.1 Lean manufacturing

The concept of “lean” first came to be widely known through the book *The machine that changed the world* by Womack et al., (1990). It reviewed the history of the development of lean manufacturing, primarily at Toyota, but was not explicit as how to implement the methodology (Moore, 2007). Other studies were undertaken more recently by authors such as Standards and Davis (1999) in their book, *Running today's factory: a proven strategy for lean manufacturing*; Liker (2004) in the book *The Toyota way* and Womack and Jones (2003) in *Lean thinking: Revised and Updated*. Key points that emerged from the work of Standards and Davis (1999) appear to be the reduction of process variability, reducing cycle time and all elimination of waste in the manufacturing process and supply chain. Liker (2004) focuses on management’s responsibility with regard to making “lean” decisions based on a long-term philosophy, even at the expense of short-term financial goals. He also emphasises production levelling, standards, employee involvement and problem solving as critical aspects of lean methodology. Womack and Jones (2003) concur with Liker’s (2004) emphasis on lean thinking throughout the organisation.

The Toyota Production System provides the basis of what is known as lean thinking (Womack and Jones, 2003). The development of this approach to manufacturing began after World War II, pioneered by Taiichi Ohno and associates while employed by the Toyota motor company (Womack and Jones,
1996). Forced to do so by shortages of both capital and resources, Eiji Toyoda instructed his workers to eliminate all waste. Waste was defined as anything other than the minimum amount of equipment, materials, parts, space and time which are absolutely essential to add value to the product (Standards and Davis, 1999). The foundation of a lean vision is focused on the individual product and its value stream and to eliminate all waste in all areas and functions within the system (Womack and Jones, 2003).

2.2.2 Lean manufacturing tools

The concept of “lean” entails the identification and elimination of process waste in order to maximise customer value (Womack and Jones, 2003). The framework of “lean” as identified by Standards and Davis (1999), Womack and Jones (2003), Piercy and Rich (2009) and Womack and Jones (2005) follows principles outlined in seven forms of waste, which must be identified and eliminated:

- Overproduction: producing products which customers do not need at that moment
- Defects: failure to conform to specifications or to customers’ needs
- Unnecessary inventory: too much stock, not needed for production or by customers
- Inappropriate or over-processing: unnecessary activities or features that do not benefit the customer
- Excessive transportation: unnecessary movement of material
- Waiting: failure to deliver products when needed downstream or employee idling, waiting for stock
- Unnecessary motion: unnecessary movements by employees.

While value stream mapping provides a graphical flow of the process and supports the related value stream analysis tool, it also provides the scope of the project by defining the current state and the future state of the system (Foster, 2007). It includes time diagrams, identifying process steps that add value as well as steps which are non-value adding, and include a communication flow from customers to supplier and a resource flow from supplier to customer (Foster, 2007, Arlbjørn et al., 2011). The authors Arlbjørn et al. (2011) and Foster (2007) are in agreement that the value stream map is essential for the identification of waste in the process and that this lean tool is of significant value in yielding speedy results in the system.

The tool known as visual management is essential for quick reference to work to standards and creating a visual environment that supports safety as well as guiding process activities. It includes 5S (sort, shine, store, standardise and sustain) activities for keeping a clean and uncluttered work area (Taghizadegan, 2006).
Error proofing, also known as Pokayoke, is a technique which reduces the likelihood of a damaging mistake. The concept was outlined by Womack and Jones (1996) as a lean tool used by Toyota to ensure product quality within the process.

Quick change over methods facilitates the reduction of lost time during product change. The principle resulted from the concept of Single Minute Exchange of Die (SMED). This was considered as impossible at the time and Moore (2007) explains that by having quick setup times, the need for batches is eliminated and less material is being wasted in the work process.

Standardised operations assist in organising and documenting the process to permit workers to effectively use material and machinery, which results in a flexible, cross functional work force within the organisation (Moore, 2007).

One piece flow is designed to reduce the size of batches or eliminates batch processing to get output to the customers more quickly while total productive maintenance ensures that factory and equipment are available so that production and service are not interrupted by equipment breakdowns (Allen and Laure, 2006).

2.2.3 Six Sigma methodology

The term, Six Sigma, refers to a statistical measure of defect rates within the system. Based on statistical techniques, it presents a disciplined and structured approach to process improvements, aiming for a reduced defect rate of 3.4 defects for every million opportunities (Antony and Banuelas, 2002, Furterer and Smelcer, 2007, Taghizadegan, 2006). Six Sigma was developed at Motorola through the efforts of Bill Smith, a reliability engineer, in the 1980s (Taghizadegan, 2006). The methodology uses a statistical theory and thus assumes that all process factors are able to be categorised by a statistical distribution curve, with the objective being to eliminate all the defects from every process, product and transaction (Antony and Banuelas, 2002). The methodology provides a structure to process improvements by offering the user a more detailed outline of Demin’s plan-do-check-act cycle, through guiding the initiative through five stages of the cycle of DMAIC(Pande and Holpp, 2002). The following sections outline each of the Six Sigma phases:

Define phase: This guides a team to define the problem effectively, correctly identify the problem and justify the commitment of expenses and resources for maximum returns. Discovering the customers’ needs, requirements, prioritising problems, activities and resources, identifying opportunities for
improvements and project goals, objectives and milestones are core outputs of the said phase (Gupta, 2005). Various tools used in the given phase are outlined by Pande and Holpp (2002). They are Pareto analysis, process flowcharts, project charter, value stream mapping and 5S to ensure that the scope of the project and the problem are adequately defined (Taghizadegan, 2006, Pande and Holpp, 2002).

**Measure phase**: This focuses on the collection of data related to the problem statement. It is imperative that the appropriate data are accurately collected to ensure their validity. Allen and Laure (2006) indicated that a tool such as the Measurement System Analysis (MSA) should be used in the measure phase to ensure accuracy (Fairbanks, 2007). Critical to Quality (CTQ) were also identified for the measurement of process inputs and outputs. A process baseline is established after which each process is measured to monitor its performance, thereby identifying opportunities for improvement (Psychogios et al., 2012). The output of this phase is the baseline sigma level and data to be used during the analyse phase to validate causes of problems (Köksal and Eğitman, 1998).

**Analyse phase**: This phase utilises the observations and collected data to pinpoint and verify the causes of variation and waste. Tools utilised in this phase include: cause and effect diagrams, Kaizen, Pokayoke, SMED, hypothesis, correlation, Anova, regression analysis and other statistical tools (Taghizadegan, 2006).

**Improve phase**: This phase enables actions to reduce variation and waste, offering the opportunity to challenge the status quo and to investigate some breakthrough solutions through idea generation and experimentation (Chookittikul and Chookittikul, 2008). Diverse statistical and non-statistical tools may be used to achieve breakthrough solutions. Frequently utilised tools include: the Theory of Inventive Problem Solving, known as TRIZ, for innovation and design of experiments to identify courses; comparative experiments to validate process changes; comparative F and t-tests and Taguchi’s Loss Function and Response Surface methodology for robust design and optimisation (Taghizadegan, 2006).

**Control phase**: The said phase ensures that the solution for the problem is sustained. In order to ensure control gains and sustain improvements it is important to inspire correct thinking about the process. The following elements constitute the activities required to implement control phases or sustain the breakthrough improvements (Fairbanks, 2007; Gupta, 2005):

- Thinking right
- Managing the process
Tools such as control charts, work instructions and visual aids are utilised during this stage in order to continuously monitor the process. Quality audits are utilised to validate process improvements and compliance with meeting the customer’s needs (Gupta, 2005).

The last aspect of Six Sigma is a formal programme that business uses to manage Six Sigma process improvement projects. In addition to and in support of DMAIC, the programme creates an infrastructure for Six Sigma process improvement (Pande et al., 2000) where various roles and responsibilities are defined. The following structure shown in Figure 2.1, employed by organisations implementing Six Sigma, was outlined by Pande et al. (2000), Pande and Holpp (2002) and Linderman et al., (2006).

**Figure 2:1: Six Sigma hierarchy (Gupta, 2005)**

The **executive sponsor** communicates, leads and directs the organisation’s overall objectives towards successful and profitable Six Sigma implementation (Linderman et al., 2006). The executive leadership has to inform the team that he or she is the driving force/sponsor and is committed to implementing Six Sigma throughout the organisation (Taghizadegan, 2006). His/her role is to support the team and
the programme. The success of the programme is based on the support of executive leadership; if the leadership doesn’t believe in Six Sigma, then the programme will not survive (Pande et al., 2000).

The champion must be one of the executive members of the organisation (Pande et al., 2000). This individual should possess the managerial and technical skills for reinforcing, planning, allocating resources and providing the necessary tools (Taghizadegan, 2006). His or her responsibility is to oversee the results of the projects and select people to be trained as master black belts and black belts in leadership to implement a world class concept and philosophy (Pande and Holpp, 2002).

Master black belts, also known as quality managers, possess knowledge of advanced applied statistical analysis, business strategy, leadership and have an extensive background in applying Six Sigma techniques (Linderman et al., 2006). Their role is to mentor and teach black belts.

Black belt(s) or team leader(s) are the technical leaders of the Six Sigma project. This individual must possess leadership and communication skills; be capable in statistics and must be given training on Six Sigma methodology, after which he or she is to be responsible for leading project teams and implementing Six Sigma (Schroeder et al., 2008).

Green belt(s) work with black belt(s) to solve problems. The individual must have statistical knowledge and be trained on basic Six Sigma concepts such as problem-solving techniques and statistical analysis (Taghizadegan, 2006).

Team members: Six Sigma’s success is based on a team approach to problem solving. Although a black belt leads the team, the team members play an important role in collecting data, bringing in ideas to solve problems and assisting black belts with some of the analysis (Pande and Holpp, 2002). The team should preferably be cross-functional, while employees of those areas where improvements are desired must form part of the team. It is preferable to have a maximum of seven and a minimum of four team members, depending on the scope of the project (Gupta, 2005).

It is imperative that an organisation implements this structure to ensure the success of Six Sigma initiatives. Antony and Banuelas (2002) emphasised that if an organisation does not have the structure in place before implementing Six Sigma, it is wasting valuable time and resources. The success of the Six Sigma programme is inextricably linked to this structure and its disciplined approach to solving problems.
Six Sigma was used in engineering education by Burge III et al. (2004) and Hargrove and Burge (2002). In their study they outlined the framework which higher education could follow to improve retention, just as manufacturing companies are able to utilise Six Sigma to improve productivity. Their work served as a foundation for this study although it differed in that it utilised a combination of Lean and Six Sigma in its investigation. This methodology can be successfully applied to engineering education as it focuses on the process. The problem-solving methodology can be utilised to solve any problem related to the process. A detailed illustration of how this methodology was used to improve engineering education processes can be found in Chapters 4 to Chapter 8 of this study.

2.3 Engineering education process

In order to apply the framework in engineering education, one needs to understand this process. In this context, a process may be described as a sequence of related activities that transforms input into output. A process output is a product or a service that is of value to the customers (Allen and Laure, 2006). There are two types of processes: manufacturing processes, comprising tangible outputs such as products and transactional processes which have intangible outputs. The education process falls in the second category.

A customer could be an end-user, or a person at the next step who uses the product or service to meet a subsequent customer’s needs. According to Patil et al. (2006), customers may be categorised as internal or external. In the education process, students and university management would be considered internal customers, while industries, parents and other stakeholders of the university would be considered as external customers (Baldrige, 2013-2014).

Baldrige (2013-2014) described students as clients while the manner in which they are taught which allows them to achieve academic results may be described as the service rendered to them by the university. However, it may also be postulated that a graduate student is a “product” which institutions sell to the future employers.
Figure 2.2 from Taghizadegan (2006) gives a clear indication of process activities.

2.3.1 Input

Inputs are independent variables that cause variation in the process. The authors Chookittikul and Chookittikul (2008) explain that the following inputs are examples of independent variables in the engineering education process:

- Students
- Teaching material
- Laboratories and their equipment
- Knowledge
- Classrooms and offices
- Information technology
- Lecture notes
- Lecturing resources, such as multimedia
- Budgeting and/or funding
- Government educational framework

2.3.2 Process activities

Activities transforming input into outputs may be categorised as two types of variables: controllable variables and uncontrollable variables.
Controlled process variables include factors such as: lecture materials, lecturing style and presentation tools. Uncontrollable variables include such factors as a student’s ability to internalise concepts, psychological learning factors, the amount of time students allocate to their studies and so forth. These variables are defined by Pande and Holpp (2002) as noise factors. As these variables cannot be controlled they are usually ignored in the analysis process. Examples of education process variables which are controllable are: teaching and learning (inputs of this process are indicated in 2.3.1), examinations and projects conducted by students (Chookittikul and Chookittikul, 2008).

TUT’s engineering education curriculum structure is designed in such a way that students who complete semester subjects become inputs for higher level semester subjects, which are in turn the next process step in the system. The programme comprises four semesters: Semester 1 (S1) to Semester 4 (S4), followed by experiential learning also known as Work Integrated Learning I (WIL I) and Work Integrated Learning II (WIL II). The final output of the process is the student who meets the external customer’s needs (those of industry); in other words, a graduate student. To illustrate this clearly, Figure 2.3 outlines the current curriculum of the Industrial Engineering Diploma at a UoT while Figure 2.4 illustrates subject relationships in the Industrial Engineering programme.

**Figure 2.3: Programme flow structure**
Figure 2.3 indicates that the outputs of each phase in the process become an input to the next process as outlined by Patil et al. (2006). It is therefore imperative that the service rendered enables students to move from one level to the next. Output is a function of the input and therefore the quality of the input determines the quality of the output, according to the view held by Chookittikul and Chookittikul (2008). Inputs must be controlled to ensure that a certain level of quality can be expected from the process. This is further illustrated by the Six Sigma equation depicted in equation 2.1 (Taghizadegan, 2006)

\[ Y = F(x) \]  

(2.1)

Where: \( Y \) is the expected outcome and \( x \) are the process inputs.

Quality and output have a direct linear correlation. Taghizadegan (2006) and Garcia (2007) showed that as soon as an organisation starts improving its processes to ensure the quality of products or services rendered, its outputs improve drastically. This concept was validated by the success of Six Sigma projects at Motorola, General Electric, General Motors and Johnsons Controls, to mention some
(Pande et al., 2000). Toyota also reported a productivity improvement of 89.1% from 1968 to 1978, for which the lean manufacturing system, which they implemented in order to improve the quality of their products, was credited (Köksal and Eğitman, 1998).

2.3.3 Output

The output of the process under consideration is the service rendered to students or that of graduate students who meet the needs of industry, depending on where in the process the output is identified.

Now that the engineering process is being discussed, it is important to discuss how quality in higher education is monitored and measured, and understanding this will lead to areas which need to be clearly identified and focused on.

2.4 Quality of higher education in South Africa

In South Africa, external quality assurance has been proposed as one mechanism of the DHET for achieving greater efficiency, effectiveness, equity and responsiveness in the higher education system (Luckett, 2007). This notion stemmed from the problem identified by DHET framework documents during 1977 and 2001, outlining historical inequalities which led to unequal standards of provision, irrelevance of the curriculum to the developmental needs of the economy, lack of access and representatively in students and staff composition, inefficiency and ineffectiveness as well as poor management (Luckett, 2007).

Quality assurance is seen as a means of ensuring high quality teaching and learning opportunities for all students, which are driven by the DHET objective to provide an equal education opportunity for all (Strydom and Lategan, 1998 and Kistan, 1999).

Quality in an education process is assessed through activities ranging from internal and external audits (curriculum reviews), which are aimed at assuring quality in the education process; tests and examinations which are aimed at validating students’ conceptualisation and the application of the subject learned (Kistan, 1999, Strydom and Lategan, 1998).

The Higher Education Quality Committee (HEQC) is an agency of the DHET in SA, whose mandate is to promote quality in higher education, audit the quality assurance mechanisms of higher education institutions and accredit programmes of higher education. Established as a result of the Education White Paper 3 (1997), it was legislated through the Higher Education Act of 1997 and formally established in May 2001 as a permanent committee of the Council on Higher Education (CHE). Thus it
is authorised by law to exercise bureaucratic power and is expected to promote the DHET’s transformation agenda (Zulu et al., 2004).

The HEQC must therefore be seen as an external arm responsible for ensuring quality assurance for South African higher education. Internally, HEIs are still responsible for managing the quality of teaching and learning processes (Luckett, 2007). The establishment of the Quality Promotion Unit (QPU) in 1995 by the Committee of University Principals (CUP) was the first step in the right direction to ensure quality within institutions. The purpose of this unit is to assist UoTs in conducting productive institutional self-evaluation at institutional and programme levels and to create a basis in the higher education system for development, in other words, promoting accreditation for purposes of articulation (Strydom and Lategan, 1998).

According to Kistan (1999), the role of the QPU is to review mechanisms and procedures used in individual institutions for monitoring and improving the quality of their programmes, and most of the UoT’s have implemented QPUs. For a QPU to be successful with regard to its mandate, the concept of quality promotion, in conjunction with quality assurance and quality improvement must be used (Zulu et al., 2004). Strydom and Lategan (1998) were of the opinion that the QPUs are able to play an important role in assuring quality within universities. While quality is everyone’s responsibility, an organisation must, however, possess a structure which facilitates quality improvement. In the case of UoTs the QPU is that structure. Although the successes of the QPUs had not been made available at the time of this research, it would seem probable that if the unit utilises the quality improvement models, they are likely to achieve some positive results (Strydom and Lategan, 1998).

Drawing from the work undertaken by Strydom and Lategan (1998), Zulu et al. (2004) and Luckett (2007), it is clear that if the quality in higher education is improved, efficiency will increase and in this manner it will meet the economic needs of industry and in turn the country’s as well as the DHET’s mandate in terms of the transformation of higher education. It is therefore of the utmost importance that UoTs ensure quality compliance as this is a catalyst for continuous improvement which yields productivity (throughput) in terms of engineering education.

Quality in the engineering education process therefore needs to be improved to ensure that output is increased. There are many factors influencing the process’s output rate and if one needs to improve this process effectively, all process steps need to be identified and mapped to ensure accuracy and identification of waste.
In order for something to be quantifiably improved, it must be measurable. Higher education, as with many other industries, has struggled to measure service quality (in teaching and learning processes). Quinn et al. (2009) suggest that units within higher education can, in consultation with their customers, define required “zero defect” objectives that are able to be measured using techniques such as statistical process control. These objectives may range from identifying lecturers coming late for class to establishing teaching and learning styles.

Another technique for measuring service quality, as outlined by Quinn et al. (2009), Tan and Kek (2004) and Hill (1995) is the SERVQUAL model. This model identifies areas for measurement of quality perceptions as:

- **Tangibles**: physical facilities, equipment and appearance of personnel
- **Reliability**: ability to perform the promised service dependably and accurately
- **Responsiveness**: willingness to help customers and provide prompt service
- **Assurance**: knowledge and courtesy of employees and their ability to inspire trust and confidence and
- **Empathy**: caring, individualised attention the institution provides to its customers.

By measuring customer expectations and perceived performance, the SERVQUAL method identifies gaps that may be targeted for improvement (Hill, 1995). These areas of measurement may then be used as a baseline for continuous improvement within the institutions (Yeo, 2009).

When comparing engineering education process inputs to areas for measuring service quality, it is clear that such inputs are very similar to areas identified for measurement by the SERVQUAL model (Tan and Kek, 2004). The SERVQUAL model indicates that in order to measure service quality, the following quality dimensions must be assessed:

- **Tangibles**
- **Reliability**
- **Responsiveness**
- **Assurance**
- **Empathy**

In engineering education, inputs from different dimensions were identified so that they can be measured and controlled, which is important because measuring process inputs and controlling process inputs result in high quality and productive processes (Taghizadehan, 2006).
In this study, quality was primarily measured by means of the Rolled Throughput Yield (RTY). This measurement determines how the process is performing by comparing the input with the outputs of the process. A low RTY suggests that process performance is not meeting customer requirements; hence the quality is poor (Taghizadegan, 2006). In order to apply LSS tools, data about the process variations need to be collected, understanding the type of data which need to be collected and in which area the data must be collected a literature review needs to be conducted on what are the factors affecting throughout within the engineering education process. If these factors are identified and controlled, the quality of the programme will improve and the throughput will increase. However, if these factors are unknown, the study cannot be focused and will result in a waste of resources.

2.5 Factors affecting engineering education throughput

In general, engineering education models predict retention from the Grade Point Average (GPA) and usually take into account factors such as facilities, funding, support structures, peer perception, extracurricular activities, academic adjustment and psychological factors (Guili et al., 2004, Hermanowicz, 2006, Cubeta et al., 2001, Schwartz and Washington, 2002). As many studies have been undertaken in these areas, a categorised summary is given in Table 2.1, outlining key work done on factors affecting engineering students’ progress. All the referenced scholars conducted research using faculty or regional or national data.

Table 2.1: Summary of factors affecting student performance in engineering education.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>National</td>
</tr>
<tr>
<td>Finances</td>
<td>(Braunstein et al., 2000, Wohlgemuth et al., 2007)</td>
</tr>
<tr>
<td>Lecture Quality</td>
<td>(Landrum, 2001, Braxton and Mundy, 2001, Lundquist et al., 2002)</td>
</tr>
</tbody>
</table>
What is clear is that there is no single solution to the throughput problem. Factors affecting throughput are complex in nature and vary between universities, regions and countries. They range from mathematical proficiency and GPA to psychological aspects such as self-efficacy and even vary between faculties and disciplines within the same university.
Although these studies identified factors affecting student performance, none of them offers a watertight solution to the problem; however, the majority of these studies are useful and may be used as a basis for investigation. The predominant conclusion is that if performance within a faculty or department needs to be improved, the uniqueness of each situation needs to be taken into account. Nevertheless, the results of these analyses were used in this study to identify factors which might be relevant to engineering education at UoTs.

After the identification of the key factors affecting throughput and data collection, solutions will need to be developed. The engineering education process is a long process. Therefore, applying a solution and waiting for data in order to validate whether the solution works or not will take much longer. This is not advisable since the process variables might change while validating the results. The proposed solution for this dilemma is simulation. A literature review on engineering education throughput improvements and simulation was conducted to serve as a foundation for this study. Below find a detailed explanation of how simulation can be applied in LSS and engineering education.

2.6 Simulation experiments in higher education

Simulation is used in LSS problem-solving methodology as part of the Improve Phase. Bubevski (2010) outlined that simulation provides for different possible outcomes, indicating the likelihood of the occurrence of each. Kelton et al., (2010) defined simulation as a broad collection of methods and applications to mimic the behaviour of real systems. This is usually carried out on a computer using appropriate software. Rossetti (2010) defined simulation as a model that represents the system in such a way that the representation assumes or mimics the system’s key applicable outward qualities. He considers simulation as the next best thing to actually observing the real system. Law (2007) referred to computer simulation as a technique to imitate the operations of various kinds of real world systems. All these definitions describe simulation as a model that represents real-life system behaviours using computer software.

According to Kelton et al., (2010), Law (2007) and Rossetti (2010) there are two different types of simulation: discrete and continuous.

**Discrete simulation:** Law (2007) defines this as modelling a system as it progresses over time by a representation in which the state’s variables immediately change at separate points in time. Kelton et al. (2010) agree that discrete simulation takes account of system changes at discrete points in time,
meaning that observations and data are gathered at a selected point in time when certain changes take place in the system.

**Continuous simulation**: Refers to modelling over time of the system by a representation in which the variable state changes continuously with respect to time. This model involves differential equations that describe relationships for the rates of change of state of the variables within time. Kelton et al. (2010) agree with Law (2007) when he indicates that continuous simulation is for continuous systems where the change in the system occurs continuously, over time.

Simulation is able to be utilised in LSS problem-solving methodology, since the purpose of the technique is to represent real-life systems using computer software. Some LSS problems are complex and solutions need to be tested before disrupting the process. Drawing from Rossetti’s (2010) definition of simulation, which, as indicated, contends that simulation is the next best thing to observing the real process or system, simulation may then be said to be useful in LSS methodology. Ferrin and Muthler (2002) outline that in DMAIC methodology, simulation can be applied from the measure phase to the control phase. When Bubevski (2009), Al-Aomar (2006) and Ferrin and Muthler (2002) applied discrete simulation to LSS problems they were solving, they all agreed that discrete simulation helped them to develop optimum solutions for their projects without complicating the process further and with less cost than that related to testing solutions.

In LSS, Design of Experiment (DOE) is used to determine optimal settings for some processes, depending on the nature of the variables (Keller, 2011). This DOE can be very expensive and in some processes, unobtainable. The researchers Ferrin and Muthler (2002) and Al-Aomar (2006) used simulation to replace DOE.

If the DOE can be replaced by simulation, then selecting the correct simulation software for the problem is important to mimic the system correctly and ensure that the results can be effectively applied in a real-life system. In order to select the right simulation software, the type of the system required to be simulated and the complexity of the system need to be understood (Law, 2007).

Based on the definition of continuous simulation (Law, 2007) and the complexity of the engineering education system, it was decided that continuous simulation would be the most suitable simulation for this study. However, the literature did not furnish examples of LSS problems in which continuous simulation was utilised.
By looking at other research where continuous simulation was used to simulate complex processes, system dynamics was found to be a simulation technique which fitted the type of system exiting in engineering education. The term “system dynamics” is defined by John (2000) as a method to enhance learning in complex systems; it helps people to learn about dynamic complexity, and to understand the source of variation, which enables people to design and develop new systems.

System dynamics is commonly associated with system thinking: one cannot develop a system dynamics model without engaging in such thinking. It is defined as the ability to see the world as a complex system, understanding that for every cause there is an effect and everything is connected to everything else (John, 2000).

The methodology is grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics and engineering. The model uses differential equations since it assumes the continuous status of the system, as indicated earlier by Law (2007). An engineering education process is a complex dynamic and a continuous process. Learning is continuous; furthermore the relationships between processes are complex and therefore system dynamics seemed to be the best type of simulation to be used to mimic this system.

In this study, system dynamics was used to simulate an engineering education system as part of the improve phase because this tool ensures that variables which affect engineering education processes are identified and the solution is tested to ensure that solutions identified are suitable to address the problem (Keller, 2011).

Engineering education processes have longer cycle durations than manufacturing or other service industries. Hence, if improvement has to be tested before implementation, a simulation method must be used to reduce the cost, time and improve quality. Consequently, for this study a system dynamic simulation method was chosen to demonstrate changes to key factors affecting student throughput.

In the LSS improve phase, independent variables affecting dependent variables had to be tested to determine the extent to which they affected the dependent variable and to determine optimal settings for these factors (Taghizadegan, 2006). The focus falls on endogenous factors within the organisation which may be tested in order to determine how the system behaves over time. John (2000) proposes that system dynamics is the best option for modelling a complex system.
System dynamics allows the decision makers and other stakeholders to experiment with various factors, variables and policies to determine the impact thereof (Richmond, 2004). It is a cheaper option than an actual experiment, which one can nevertheless build and gather data from.

If simulation models are not used, it is very difficult to predict the outcomes of certain policy decisions, without actually implementing the decision prior to assessment of the impact, particularly if the system is as complex as engineering education. Richmond (2004) explains that implementing decisions without testing them might be a costly exercise to the community, and may in certain circumstances be catastrophic for organisations.

An Engineering Higher Education System is complex due to having many stakeholders, linked with information, the resource flow and behavioural issues are characterised by endogenous and multiple feedback loops (Oyo et al., 2008c). System dynamics has been used to improve resource management (Kennedy and Clare, 1999) and to examine funding as well as the quality of higher education (Oyo et al., 2008c).

Kennedy outlined a taxonomy based on a survey of completed system dynamics investigations in higher education in 1999; the results of which are presented in Table 2.2.

<table>
<thead>
<tr>
<th>Hierarchical Level</th>
<th>National</th>
<th>Regional</th>
<th>University</th>
<th>Faculty</th>
<th>School</th>
</tr>
</thead>
<tbody>
<tr>
<td>External Forces &amp; Legislation</td>
<td>(Green 1994, Mackintosh et al., 1994, Gornitzka and Maasen, 2000, Robertson, 1999)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.2: Kennedy’s taxonomy of system dynamics in higher education
Frances et al., (1994) reported that most work undertaken in system dynamics in higher education is related to planning, budgeting and resources at university level, followed by work on enrolment at national and university level and lastly on teaching quality and teaching practice. More work on planning, budgeting and resources has been performed by others such as that done by Oyo et al. (2008b), Oyo et al. (2008c) and Oyo et al. (2008a) since 1999, when Kennedy (1998) and Kennedy and Clare (1999) carried out the above-tabled study. From Kennedy’s report and from recent writing, it is clear that no work using dynamic models has been done at university or national level concerning efficiency improvement. Most of the work that focused on the latter was at primary and high school level, as depicted in Table 2.3., making it clear that as far as universities or higher education are concerned, none of the studies focused on improvement in efficiency and facilities and or the quality of infrastructure.
Table 2.3: Taxonomy of system dynamics in the education system as regards efficiency and enrolment improvement

<table>
<thead>
<tr>
<th>Hierarchical Level</th>
<th>National</th>
<th>Regional</th>
<th>University</th>
<th>Primary School</th>
<th>High school</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improving Enrolment</td>
<td>(Pedamallu et al., 2012, Pedamallu et al., 2010a)</td>
<td></td>
<td>(Pedamallu et al., 2010a, Pedamallu et al., 2010b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Facilities and Infrastructure Quality</td>
<td>(Pedamallu et al., 2010b)</td>
<td>(Pedamallu et al., 2010b)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Models developed by Oyo et al. (2008c), Oyo et al. (2008b), Oyo et al. (2008a) and Altamirano and Daalen (2004) for primary and high school education dealing with efficiency, improving enrolment, facilities and infrastructure, were used as the basis for the development of a model for tertiary education in this study. This model focused on indigenous factors within the university which might affect student throughputs such as: promotion; quality of learning and scholarly hours. The model developed by Altamirano and Daalen (2004), mentioned above, which focuses on education demand, teachers and infrastructure as well as on resources required to improve secondary and primary schools in Nicaragua, differs from this researcher’s model as it investigated national factors and policies and is concerned with school coverage and levels of illiteracy in Nicaragua. Although system dynamics models have been developed for primary and secondary education by different authors (Terlou et al., 1991), models in higher education student performance are scarce. Altamirano and Daalen (2004) focus on predicting the number of primary schools, high schools and literacy levels in Nicaragua, investigate funding policies which must be improved in order to reduce levels of illiteracy and primary and secondary school coverage in that country. They also address the issue of the low efficiency of primary education in Latin America, examining factors related to quality of learning, school attendance, actual hours of pupils attending school and hours of absence and factors affecting dropout.
Pedamallu et al. (2010a) and Pedamallu et al., (2012) consider the impact of infrastructure facilities on the quality of primary education in a developing nation. The study emphasises that a lack of infrastructure results in poor enrolment and even dropout due to the long distances that must be travelled between residential areas and primary schools. In higher education systems, dynamics have been studied by various researchers (Frances et al., 1994, Oyo et al., 2008c, Kennedy, 2002). These researchers used proposed system dynamics tools to model policy changes related to planning, budgeting, resource allocation, funding and quality. Their studies concentrate on the impact of part-time lecturing, staff to student ratios, staff development, research productivity and the perceived quality concerning university funding and quality. Their findings indicated that university funding and quality are complex phenomena and there is no one solution that fits all universities. However, the model provides guidelines for universities on how and where to invest in research in order to improve quality.

As indicated in Table 2.2 the researchers Kennedy and Clare (Kennedy, 2002, Kennedy, 2000, Kennedy and Clare, 1999) investigated how system dynamics can be used in higher education in order to improve resource management, identifying potential dynamics on which higher education can focus in order to manage the hard and soft issues related to resources within the higher education system (Kennedy, 2000; Kennedy, 2002; Kennedy and Clare, 1999). The researchers, Frances et al., have utilised system dynamics to improve planning and budgeting in higher education (Frances et al., 1994). In their study different policy scenarios were presented to inform Houston’s planning and budget allocation for their universities, while in Arizona this technique revealed a new focus area for the team if they wanted to improve enrolment. The system dynamics model had not previously been studied with a view to improving throughput or efficiency in higher education. Therefore the current study was built on by Terlou et al. (1991) which examined the possibility of improving efficiency of primary education in Latin America.
2.7 Summary

In this chapter, literature concerning LSS, engineering education, factors affecting student performance and simulation were discussed. The application of these methodologies in engineering education was also considered. It is clear from the literature that previous applications of LSS in engineering processes are rare and the few authors who have used it in engineering education concentrated on the conceptual framework and not on application or implementation. Factors affecting student performance vary from faculty to faculty as a consequence of engineering education being a complex phenomenon involving various factors and there is no one solution which can ameliorate all retention problems.

This work utilises LSS to determine focus areas for the faculty at TUT by identifying key variables affecting student performance and proposes a solution based on the findings. The use of simulation in the Six Sigma was based on the proposal by Ferrin and Muthler (2002), who indicated that simulation may be used to save company resources, which might have been wasted should this testing not have been done.

It became evident that system dynamics was used mainly to simulate efficiency in primary and high school education. In tertiary education the focus has mainly been on planning, budgeting and resources. The issue of improving throughput of tertiary institutions has not been previously addressed. The next chapter introduces the methodology followed in this research.
Chapter 3: Research Methodology

3.1 Introduction

This chapter describes the methodology followed in the attempt to answer the research questions posed in Chapter 1. The chapter starts off with a description of the chosen method, LSS methodology and its implications for this research. The given methodology is outlined and the tools used per phase are discussed. An explanation of how this methodology was used to find solutions to throughput problems in engineering education is documented. Figure 3.1 indicates general LSS tools used in solving problems.

Figure 3:1: LSS road map for problem solving (Gupta, 2005, Keller and Pyzdek, 2005)

In this research not all the available tools were applicable to the education processes. Engineering education is a transactional process and the type of tests carried out is determined by the nature of the data collected. The applicable LSS tools used in this research, indicated in Figure 3.2 were: Define Phase (Business Case, Problem Statement, Primary and Secondary Metrics, High-level Process Flow, Pareto Analysis and Project Charter); Measure Phase (Detailed Process Flow, Measurement System Analysis, Cost of Poor Quality, Data Collection); Analyse Phase (Cause and Effect Diagram and C&E Matrix, Failure Mode and Effect Analysis, Correlation, Regression Analysis, Box Plots, Pareto Analysis); Improve Phase (Hypothesis testing: T-tests, 2 sample T-test, Anova Test, Paired test, Design of Experiment, Simulation, Cost-benefit Analysis); Control Phase (Control Plan, Pokayoke, Design for Lean Six Sigma, SPC Charts, Document Review, Monitoring Plan, Review Results).
Diagram, Correlation, Regression Analysis, Box Plots); the Improve Phase (Causal loop and Simulation) and the Control Phase (Control Plan, Document Review, Monitoring Plan and Review Results).

3.2 Research design

The research design is the logic that links the gathered data to the questions underpinning the study. The research project logic is the paradigm that provides insight into the community of facts. According to Depshande (1983), understanding the nature of a paradigm enables researchers to determine what problems are worthy of exploration and what methods are available to solve them. Two popular types of research paradigms are found in qualitative and quantitative studies. Both paradigms guided the process followed in this study in gaining an understanding of the research questions in Section 1.2 of Chapter 1 in order to achieve the objectives.

**Qualitative research method:** Qualitative research, according to Denzin and Lincoln (2005), involves the study, use and collection of a variety of empirical materials such as case studies; interviews; artefacts; cultural texts and products; observational, historical, interactional and visual texts that describe routine and problematic moments and meaning in the lives of individuals. Accordingly, qualitative researchers deploy a wide range of interconnected interpretive practices, hoping always to obtain a better understanding of the subject at hand. It is understood that each practice makes the world visible in a different way. Hence there is frequently a commitment to use more than one interpretive practice in any study. In this research, qualitative research was employed to study the current process parameter in engineering education. The output from this was used to develop a system dynamics simulation model Denzin and Lincoln (2005).

**Quantitative research method:** Quantitative research, also known as descriptive research, was defined by Leedy and Ormrod (2005) as research which involves either studying the characteristic of an observed phenomenon or exploring a possible correlation among two or more phenomena. Creswell and John (1994) defined quantitative research as an enquiry process based on testing a theory composed of variables, measured with numbers and analysed with statistical procedures in order to determine whether the predetermined generations of theory hold true. In this study, quantitative research was used to collect and analyse necessary data with a view to developing and validating solutions to throughput problems in the engineering education process.
3.3 Research methodology

The FoEBE of the TUT, Pretoria, was used as a case study. The research seeks to identify key elements affecting throughput in engineering education using LSS tools. Identifying these key elements will assist the university in allocating resources in order to maximise productivity, resulting in an increased throughput of graduates where it matters most and this would result in throughput improvement.

The FoEBE has seven departments: Industrial Engineering, Mechanical Engineering, Electrical Engineering, Chemical and Metallurgical Engineering, Civil Engineering as well as Building Science and Architecture. Diploma programmes offered are the three years programme with two years of theory and one year of WIL for engineering qualifications and six months WIL for the built environment qualifications.

Applying LSS to improve the faculty throughput required that all departments within the faculty function as a unit moving in the same direction. The 2010 data indicated that the faculty houses 10 895 students, 235 full-time and part-time academic staff members and 60 support staff members. Therefore, implementing an LSS project to improve throughput within the faculty would have been an impossible task if all the departments were simultaneously involved in this project. To implement this systemically, the focus was placed on the department with the lowest number of students graduating from the faculty, as per the data in Figure 4.2 in Chapter 4. LSS tools (DMAIC) were used as a problem-solving methodology in this study. Figure 3.2 shows the LSS tools applicable to each phase in the order of application:

![Figure 3.2: LSS tools applied in each phase](image-url)
3.3.1 Define phase

In the define phase, the project charter was developed. Such a charter outlines the business case, problem statement, project goals, primary and secondary metrics, high-level process flow and Supplier Input Process Output Customer (SIPOC) analysis (Taghizadegan, 2006). A high-level process flow was therefore developed. The detailed define phase description is provided in Chapter 4 and Appendix A.

3.3.2 Measure phase

In the measure phase, a detailed process flow was developed, MSA was determined and the data collection plan was developed and executed.

3.3.2.1 Process flow

In the measure phase, engineering education processes were observed and a detailed process flow was developed in order to determine bottlenecks in the system or to identify opportunities for improvement.

3.3.2.2 Measurement system analysis

Measurement system analysis was utilised to validate the data collection process. This study utilises gage reproducibility (R) and repeatability (R) analyses to determine if data were collected precisely and accurately (Keller, 2011). After a gage R&R was approved, a data collection plan was developed and the data were collected.

Data collection

The following data collection strategy was used in this study:

The faculty institutional data: this data was collected from the university information system. Types of data used were: student’s admission grades, pass rates, progress reports and exclusions.

Survey questionnaire method: questionnaires were sent to 550 sampled students. A follow-up call was made to provide feedback and obtain clarification of information. The data was collected from respondents by e-mail, fax or hard copy.

Interviews with students: in order to understand certain variables from data collected through the questionnaire, group discussions and interviews were conducted with sampled respondents.
Sample design

Research population
The population is defined as the total collection of elements about which one wishes to make some inference (Leedy and Ormrod, 2005, Cooper and Schindler, 2008). The research population was that of all the students of the TUT in the FoEBE studying the National Diploma programme from 2009 to date.

Sampling methodology
Leary (2004) defines sampling as “the process by which a researcher selects a sample of participants for a study from the population of interest”. There are two broad methods of sampling: non-probability sampling methods and probability sampling methods. This study utilised non-probability sampling techniques, where the sample members were not randomly selected. There are four types of such sampling methods: convenience, judgment, quota and snowball sampling (Hair et al., 2007).

This study utilised judgement sampling, also known as purposive sampling, where an experienced individual selects the sample based on his or her judgement about some appropriate sample characteristics required by the sample unit (Hair et al., 2007). Extreme and deviant case sampling techniques are used. This involves learning from notably unusual manifestations of the phenomenon of interest such as outstanding successes, notable failures, top of the class, dropouts, exotic events, crises (Cooper and Schindler, 2008). In this data student dropout rates, exam statistics and success rates are used to identify possible causes of the subjects’ failure statistics and poor throughput.

Of the total population of students at TUT, only certain of the faculty’s students were selected for the research sample. Students were selected based on the researcher’s knowledge of their progress in their studies so as to provide the most value to the study. The sample consists specifically of students who dropped out of the programme, yet who were in the system at least for a year. The sample selection was thus based on the following criteria:

- Students from the said faculty who have been in the programme for more than a year and
- Students from this faculty, who had dropped out of the programme.

The researcher was employed in the organisation, ensuring easy access to people and information and enabling direct contact by e-mail or telephone.
**Sample size**

Sample size was determined by time and budget. Since some of the respondents were “dropout” students of TUT, issues of time and budget to collect data were of significance. A sample of 500 students studying at TUT plus 50 students who had dropped out of TUT was selected for the study. The historical data of students sampled in the system were used for analysis and new data were collected during the research as required.

**Measuring instruments**

The following three measuring instruments were used in this study:

1. **Questionnaire**: A survey questionnaire approach was used for this research to collect data about factors contributing to students’ failure in different subjects. The questionnaire comprised two sections, A and B. Section A dealt with biographical information whereas Section B dealt with factors affecting performance, comprising: 15 closed questions that assessed factors contributing to students failing subjects; 17 closed questions assessing factors contributing to students dropping out of the programme of the university and three open-ended questions.

   The closed questions were designed to ensure accurate data were collected and students were asked to rate their answers using a four point Likert scale, ranging from 0 = not at all and 4 = to a greater extent.

   However, the open ended questions offered students the opportunity to contribute towards the improvement of the faculty by suggesting areas of improvement they thought necessary in order to improve throughput.

2. **Focus group study**: According to Leedy and Ormrod (2005) (Leedy and Ormrod, 2005) using focus groups is a method of collecting data when conducting qualitative research. This technique involves gathering a group of people to discuss a particular issue for an hour or two. A moderator introduces the issues to be discussed, ensures no one person dominates the discussion and keeps people focused on the topic. This technique was used when utilising LSS tools to validate variables identified from the questionnaire results. Six Sigma methodologies require a cross functional team to work together to solve a proposed hypothesis, therefore the focus group method was appropriate for this purpose.
3. Interviews: Interviews were used to source information, particularly during system dynamics model building. In order to understand how some variables work together and to collect data which were not in the institution’s system, interviews with relevant stakeholders were used as advised by Richmond (2004).

This method was useful and prevented delays which could have been experienced when applying the methodology.

Reliability and validity

Validity and reliability are important to ensure the accuracy and precision of the data collected.

1. Reliability: According to Leedy and Ormrod (2005), “reliability deals with accuracy. It relates to how accurate the instrument is.” In order to enhance both content and face validity, the study utilised an adapted instrument along the lines implemented by Cooper and Schindler (2008), where both an extensive literature review and preliminary qualitative interviews with subject experts were used to provide relevant information.

2. Validity: There is no statistical test to verify the validity of the data. Hair et al. (2007), point out that “validity is concerned with the soundness, the effectiveness of the measuring instrument. Validity tries to identify exactly what the test should measure and whether it does actually measure this.” According to Leedy and Ormrod (2005) and Render et al. (2009), there are several types of validity measures, two of which are appropriate for this research:

   Face validity: This type relies on the judgement of the researcher. The researcher must ensure that the instrument is measuring what it was created to measure and that the sample is adequate to be representative of the behaviour or trait being measured.

   Content validity: This validity looks at the “content” being studied, namely, how accurately the actual questions elicit the information required to complete the study.

To ensure face validity and content validity, the researcher has to conduct a survey pilot test, where the questionnaire is distributed to a selected list of respondents to test for practicality. By adopting such a survey questionnaire as outlined by the latter authors, and based on inputs from a pilot test, it was possible to enhance internal consistency through the use of constant sum and Likert-like scales rather than content analysis resulting from open questions. From the pilot test where respondents selected answers from a limited range of clearly defined alternatives, errors were reduced in terms of equivalence and stability (Cooper and Schindler, 2008, Render et al., 2009).
It is also important that the survey is pre-tested and revised as needed. In this regard a pilot questionnaire was distributed to selected respondents from both faculty and “dropout” students who had been in the programme for more than a year. Inputs obtained from these pilot participants were used to make the necessary changes to the questionnaire prior to the survey being formally conducted. These insights included ambiguity, vagueness, time needed to complete the questionnaire and items of sensitivity amongst the initial questions that may have presented problems for the respondents.

### 3.3.2.3 Sigma level

In order to determine the sigma level, the research baseline was established for the project as depicted in Figure 3.2, utilising data on students dropping out, students failing subjects as nonconforming students for a cohort entering TUT in 2004. A sigma value of 1.68 was obtained and used as a baseline process performance for this project. Section 5.7.2 contains more detail on this aspect.

### 3.3.2.4 Cost of poor quality

The cost of poor quality was calculated; this entails the cost incurred due to poor quality service. This cost is made up of internal failure costs related to issues such as waste of time and operational expenses carried by the university when students who are in the system fail the subject. External failure cost is related to such items as the loss of grant opportunities by the university as a result of poor students. Section 5.7.2.2 contains more detail on this aspect.

### 3.3.3 Analyse phase

#### 3.3.3.1 Statistical analysis

In the analyse phase the Statistical Product and Service Solutions (SPSS) 16 and Minitab Version 16 statistical software were used for the analysis of the primary data and inferential statistical tests were carried out:

Cronbach’s alpha test (reliability test): In this research the Cronbach’s alpha test was carried out because it is widely used in establishing the internal reliability of a set of questions. Generally, an alpha of 0.60 or higher is thought to indicate an acceptable level of internal consistency (Ho, 2006). All the factors in the survey instrument (questionnaire) were checked against the Cronbach’s alpha coefficient to establish whether they were up to 0.50.
Chi-square tests: The Pearson Chi-square method of analysis was used to test the association between categorical variables together with frequency distributions and their correlated percentages. A chi-square is a statistical measure used to test hypotheses on patterns of outcomes of a random variable in a population (Ho, 2006). The patterns’ outcome is based on frequency counts of categorical random variables.

Hypothesis test (Sample T-test): The 2 sample T-test was used to test equity of the mean between two variables.

3.3.3.2 **Cause and effect analysis**

A cause and effect diagram was used to analyse the problem. The Ishikawa, cause-effect diagram or fishbone diagram, helps to work backwards from the problem to diagnose root causes. There are two types of fishbone diagrams. The first is generic with six categories used to identify possible areas where the cause of the problem may be namely people, process, machines, materials, measurement and environment and the second type is a step-by-step fishbone that begins with the first step and works backwards because errors found in early steps in the process often cause the biggest effect. The fishbone is also helpful in validating key factors affecting throughput by isolating a vital few from many trivial ones.

3.3.3.3 **RTY and network function techniques**

RTY and network function techniques were used to analyse the data to determine process performance and focus areas.

3.3.4 **Improve phase**

The purpose of the improve phase is to determine to what extent the identified X (potential root causes) affects the Y (the outputs).

3.3.4.1 **Simulation**

Measurable factors affecting throughput were simulated to determine optimal improvements possible using system dynamics, Stella version 9.14 and Vensim to simulate key variables (John, 2000, Richmond, 2004, Ventana systems, 1988-2013).

3.3.4.2 **Intervention**

An intervention is a combination of programme elements or strategies designed to produce behaviour changes or improve their health status among individuals or an entire population (Health.mo.gov, 2013). Therefore an intervention approach was used to determine the impact of
implementation of the proposed solution within the faculty. Interventions may include educational programmes, new or stronger policies and improvements in the environment or a health promotion campaign. Interventions that include multiple strategies are typically the most effective in producing desired and lasting results. Interventions may be implemented in different settings including communities, work sites, schools, health-care organisations, faith-based organisations or in the home. Interventions implemented in multiple settings and using multiple strategies may be the most effective because of the potential to reach a larger number of people in a variety of ways.

Evidence has shown that interventions create change by:

- Influencing individuals’ knowledge, attitudes, beliefs and skills
- Increasing social support
- Creating supportive environments, policies and resources (Health.mo.gov, 2013)

In this study, interventions were implemented in certain departments of the said faculty which share subjects, to ensure coordinated improvements as per the definition above.

### 3.3.5 Control phase

The control phase deals with putting controls in place to ensure that realised improvements do not revert back to the way things were before (Gupta, 2005). A control plan was developed for this study. Key controls were placed in the system and documents using the electronic resource internal portal named myTUTor at TUT.

Documents were reviewed to ensure consistency among the key players and this formed the standardised documents (research findings) which were uploaded on the university internal portal used by lecturers to communicate with the students and document learning material.

This gave accessibility to the documented findings and utilisation. Periodic audits must be carried out to enforce compliance.

### 3.4 Limitations

LSS methodology relies on data in order to make scientific analyses and progress to decision making. Data collection from other UoTs was a challenge hence only data from TUT was used for the analysis. The findings of this study, however, are not limited to TUT since engineering education processes in SA are similar.
Only quantifiable variables were considered in this study since student performance may be affected by psychological issues as well. All such issues are considered as noise factors for the purpose of this study.

The engineering education cycle is long and it takes six months to a year to determine results of improvements, in some cases even longer. Simulation was therefore used to overcome this limitation.

In the area where the questionnaire was used as a data collection technique, questionnaires were sent to 550 respondents. There was a limitation placed on time allocated to complete the questionnaire.

### 3.5 Assumptions

The following assumptions were made for this research:

- Respondents would be available to complete the questionnaire.
- An acceptable response rate is about 70%, which equates to about 385 respondents.
- Respondents, who did respond, were representative of the department.
- Respondents who have been in the programme for more than a year have enough experience to contribute effectively to the study.
- Students who dropped out would be willing to share honestly with the faculty their personal situation that caused them to drop out.

### 3.6 Ethical considerations

Ulin et al. (2002) state that when a researcher encourages people to talk openly to him or her, one incurs serious ethical obligations to them. The researcher was aware of this fact and therefore TUT ethical policy guidelines were followed to protect the confidentiality of the study participants and to encourage them to be forthcoming with information.

All study participants were provided with information relating to the aim and methodology of the research prior to the data collection, ensuring that participation was voluntary. They were required to sign the informed consent form if they agreed to participate in the study.

All primary data collected in the form of narratives were deemed to be confidential and were utilised by the researcher only.
No individual names of participants were used in the final aggregated text. Where verbatim quotes were used, the researcher used the generic students’ department where they were registered to reference the quote.

The researcher was available to the participants in the study at all stages of the research process and answered all questions or concerns.

The researcher at all times reported her findings in a complete and honest fashion, without misrepresenting what she had done. She did not intentionally mislead others as to the nature of her findings. Under no circumstances did the researcher fabricate data to support a particular conclusion, no matter how seemingly “noble” that conclusion may have appeared. Appendices A to E address the details regarding ethical issues/approval.

3.7 Summary

The purpose of this chapter was to describe and justify the chosen methodology and research process in detail. A detailed discussion of the development, structure and properties of the measuring instrument used in the study was preceded by a section covering the research design, including the sample structure and measuring instrument, as well as by a description of the sample, and how it was obtained.

The final section covered the data collection and processing procedure, and the analysis, reliability and validity of the statistical measurements were discussed. The assumptions and limitations of the study were also discussed. The chapter concluded by addressing the ethical issues involved with research of such a nature.

In the next chapter the define phase is explained, as is the way in which this was applied to the engineering process.
Chapter 4: Define Phase

4.1 Introduction

In this chapter a detailed description of the define phase and the content of the project charter are discussed, while their application to engineering education will also be outlined. The given phase is of the utmost importance since it determines the course and direction for the project (Buch and Tolentino, 2006). If the project definition is not carried out correctly, the project will be delayed and time will be wasted investigating the wrong problem (Kalemkarian, 2006). Keller and Pyzdek (2005) delineate the key objectives of this phase as:

- Project definition: to articulate the project scope, goals and objectives, team members, sponsors, project schedule and its deliverables.
- Top level process definition: to define the project’s stakeholders, inputs and outputs and its broad functions.
- Team formation: to assemble a highly capable team and focus their skills on a common understanding of the issues and benefits of the proposed project.

In the define phase the project charter must be developed to serve as a contract between the project sponsor and the project team (Pande and Holpp, 2002). This document is a living one in the sense that as the project continues through the DMAIC phases and new information is established, the document must be updated accordingly (Keller, 2010). It is then used to manage and continuously focus the project over its lifetime.

4.2 Business case

Morgan and Brenig-Jones (2012) point out that the business case of the project must address the impact of the project on business needs, should the project be successful. This might be in terms of cost, customer satisfaction and employee impact. Keller (2011) argues that a good business case must answer the following questions:

- Why must we care?
- If this project is not solved, what do we lose?
- Is it worth investing time and resources in this project?
A good project should be linked to the strategic goals of the organisation. This alignment is imperative for the project and business success. Good projects must solve customers’ problems and the business case must explain why a project must be undertaken (Morgan and Brenig-Jones, 2012).

4.3 Problem statement

Gupta (2005) emphasises that the first element of the project charter is the problem statement. Defining a problem in terms of quantitative aspects in LSS is of paramount importance. This ensures that there is justification for the project selected and that resources may be allocated to solve the problem (Morgan and Brenig-Jones, 2012). It also eliminates vague, obscure problems which management and engineers might assume are of significance but are without data to validate them (Gygi and Williams, 2012).

A good problem statement summarises the problems to be addressed: it states the current and historical conditions of the process and specifies, in a quantitative way, the waste incurred by the organisation as a result of poor performance of that process (Keller, 2010). Historical data must be gathered and used at this stage of the project if actual process performance data are not available (Keller, 2011).

4.4 Project objective

The project objective is a specific statement of the outcomes desired, which must explain where the team envisages the process to be after completion. Keller (2011) provides guidelines for establishing the project objective; if the process is operating at or less than 3 sigma level of performance, then the objective should be a 10 times reduction in defects.

4.5 Project scope

The project scope refers to specific aspects of the problem that will be addressed. When developing such a scope, consideration must be given to the problems which need to be solved and the process thereof (Gygi and Williams, 2012). The project scope must not be too ambitious to prevent the project from becoming too big and too difficult to finish in the reasonable time, such as an LSS research project must take to complete (Kalemkarian, 2006). Tools such as Pareto analysis and process mapping are used to scope the project effectively. It is important that a project’s scope be adjusted when it goes through the DMAIC phases if it is established that it is becoming too big and there are too many metrics to be solved (Gygi and Williams, 2012).
4.6 Primary and secondary metrics

A metric is a measured parameter from the process that provides some indication of the state or condition of the process (Burge III et al., 2004). For a given process, several metrics can be identified and be used to monitor process performance. They may be divided into primary and secondary metrics.

Primary metrics comprise the main interest of the study while secondary metrics measure potential changes in the process as a result of altering the primary metrics.

4.7 High-level process flow

High-level process flow gives a bird’s eye view of the process, or to put it differently – an overview of the process; it documents the process activities. Process flow, an approach that graphically represents the process, assisting people to more readily understand the said process, makes a complex process appear easy (Taghizadegan, 2006). The process map also indicates the functional responsibilities for each process step.

4.8 SIPOC analysis

According to Gupta (2005), in LSS methodology, SIPOC analysis in the define phase is critical to ensure that the process is better understood by the team. SIPOC is defined as a process map which outlines all aspects of the process, from suppliers to customers (Keller, 2011).

4.9 Application of define phase in the engineering education problem

This aspect of the work focuses on applying the LSS tools described in Section 4.1 to Section 4.7 in a stochastic scenario. In engineering education the problem definition was not different from that in any other LSS projects. The process started at the define phase, a problem definition was devised and the initial project charter was developed. The details of the define phase of this project are discussed in the next section:

4.9.1 Business case

Improving student throughput is important for the FoEBE because funding for the faculty is based on the number of students enrolled for its subjects and those completing the programme. The faculty loses about R30,418.49 in potential income (detailed calculation in Section 5.7.2.2 refers) per student
each time he or she repeats a subject. Furthermore, students failing are preventing other students from obtaining a place at the university since resources are scarce and it exacerbates the situation where industry needs engineers and technologists. It is thus important for the faculty to solve the throughput problem for the sake of viability and alignment with the national objectives for higher education in South Africa which state that the long-term goal of increasing the overall participation rate of producing graduates must be complemented by strategies to increase graduate outputs in the short to medium-term in order to ensure that the current demand for high-level managerial and professional skills is satisfied (Andrew, 2005).

### 4.9.2 Problem statement and project goal

From the historical data, the analysis reveals that the Department of Industrial Engineering throughput rate for the National Diploma programme at TUT was 14% for 2009 (Table 4.1). The report compiled by Scott et al. (2007) indicates that the national throughput rate for all Engineering National Diploma programmes of UoTs in South Africa is at 17%. The department’s throughput rate is way below the national level. It highlights the severity of the problem as 17% is too low for a developing country. As mentioned in Section 1.2, the goal is to apply a comprehensive LSS framework to the engineering education process and to identify where scarce resources should be focused to obtain optimal throughput improvements using a unified systematic approach. If applied, this will result in an increase in the throughput rate of at least 10% for the department by 2017. This improvement is important in order to increase the viability of the department, as well as the faculty, and to meet national strategic goals.

<table>
<thead>
<tr>
<th>Table 4.1 Industrial Engineering department throughput rate 2007 to 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Years</strong></td>
</tr>
<tr>
<td>Throughput Rate</td>
</tr>
</tbody>
</table>

Source: Support (2013)

### 4.9.3 Project scope

Although the FoEBE houses seven departments, this project focused on the Department of Industrial Engineering since it reports the lowest throughput rate of students who graduated from 2004 to 2009, as indicated in Figure 4.1. This amounts to a graduation rate of 26% (number of graduates divided by number of registered students), with Electrical Engineering being the best performing department in the faculty in terms of numbers of students that graduate. In comparison, a study by Beer (2009)
revealed that the retention rate data for Industrial Engineering was 20% while Electrical Engineering had a 36% retention rate. From this data and the fact that Industrial Engineering is a small department, if changes to the system are required, they can be easily implemented. Therefore, it was decided to start with the Industrial Engineering department and then roll results out to other departments after solutions have been validated.

Figure 4.1: Faculties’ cumulative number of students registered, dropped out and graduated from 2004 to 2010 (Support (2013))

A Pareto analysis compiled from the 2004 to 2010 data (Figure 4.2) indicates that the main variables affecting student throughput in the Industrial Engineering department, which have been prioritised from variables listed in the data collection section, are:

Priority 1: \(X_1\) Student subject failure
Priority 2: \(X_2\) Student dropout
Priority 3: \(X_3\) Students not getting/waiting for WIL I or WIL II
Priority 4: \(X_4\) Student failing WIL I or WIL II
The Six Sigma equation (Taghizadegan, 2006) is given by

\[ Y = F(x) \]  \hspace{1cm} (4.1)

where:

\[ x = x_1, x_2, x_3, \ldots, x_n \] are process variations and \( Y = \) Throughput rate.

Variables which were found from the Pareto analysis to make a major contribution to student failure are \( x_1 \) (students subject failure) and \( x_2 \) (students drop out) as shown in Figure 4.2. Variables \( x_3 \) to \( x_n \) do not make a significant contribution to student failure; however, they will be included in the analysis for further investigation.

### 4.9.4 High-level process flow

Figure 4.3 indicates the high-level process flow of an engineering education process. A high-level process map assists in understanding the process better. Because the process has been evaluated, many previously unknown aspects are revealed; hence potential opportunities for improvement are identified (Keller, 2010). The process flow gives a bird’s eye view of the entire process. The project starts when a student applies to study at TUT and ends when he or she graduates. The swim line process map in Figure 4.3 affords an overview of the process which results in customers’ needs being met, meaning students are progressing from one level to the next. It also assists in identifying possible areas of intervention highlighted in red (Figure 4.3), which the faculty and the department are able to control. Figure 4.3 was developed by a researcher.
4.9.5 SIPOC analysis

A SIPOC analysis is used to identify potential $x_s$ which might have an impact on $Y$. The purpose of this analysis is to ensure a better understanding of the process and to ensure that all possible variables are accounted for during the analyse phase. Figure 4.4 indicates the developed SIPOC analysis for the engineering education process.
4.10 Summary

In this chapter, the define phase was outlined as per the DMAIC requirements, the problem statement was established, project goals were outlined, the business case was discussed, project scoping was done and the team was formed. All this was applied to the engineering education process which this project was intended to improve.

The define phase of this project was no different from that in any other process improvement project, although the engineering processes are longer than other processes and project scoping was found to
be useful in narrowing the project down. The detailed project charter was compiled and is attached as Appendix A.

The studies by researchers Keller (2010), Keller (2011), Keller and Pyzdek (2005), Burge III et al., (2004), Hargrove and Burge (2002), Does and de Koning (2008), Chookittikul and Chookittikul (2008), Morgan and Brenig-Jones (2012) and Kalemkarian (2006) demonstrated that the define phase is an important phase in a Six Sigma project. Within the engineering education context they indicated that a clear and quantifiable problem statement and objectives are essential for the given phase to be completed. In this study more define tools were used which are normally applied in the industry context, such as the high-level process map, SIPOC analysis and project scope using Pareto analysis and developing a business case which justified why the research needed to be conducted.

The measure phase is discussed in the next chapter. In the DMAIC approach to the problem-solving steps, the measure phase may begin after the project has been defined and resources allocated for the project. The purpose of this phase is to determine the cost of poor quality, validate the measuring system and formulate the data collection plan. This is essential in Six Sigma since all decisions made must be based on data.
Chapter 5: Measure Phase

5.1 Introduction

The define phase was discussed in the previous chapter. The main components of this phase such as the business case, problem statement, project goals and scope, metrics, high-level process flow and SIPOC analysis were outlined and applied to the engineering education process. A process performance of a 14% throughput for the year ending December 2010 for the Department of Industrial Engineering was ascertained, while the goal statement of applying a comprehensive LSS framework to the engineering education process and identifying where scarce resources should be focused to obtain optimal throughput improvements, thereby improving the process by 10%, was established. In this chapter the emphasis falls on the measure phase of the DMAIC process which involves detailed process mapping, MSA, data collection, the cost of poor quality, process baseline, sigma level and metrics to be improved.

The main purpose of the measure phase is to validate the MSA and collect accurate data to be used in the analyse phase (Morgan and Brenig-Jones, 2012). LSS process improvement is about using common sense and data to solve problems. This chapter is structured in such a way that Sections 5.2 to 5.6 explain the tools which were utilised in the measure phase in line with the study, while Section 5.7 documents how the measure phase was applied in the engineering education environment.

5.2 Detailed process flow

While a high-level process map was developed during the define phase, it lacks the detailed decision points which characterise the complexity of the process (Keller, 2011). In LSS problem-solving methodology, a detailed process mapping of the current process “as is” is required in order to understand the process and to scope the project more effectively if required (Taghizadegan, 2006). An “as is” process map identifies the Kaizen or continual improvement areas within the process (Morgan and Brenig-Jones, 2012), allowing the areas needing improvement to be quickly and easily noticed. This Kaizen blitz may offer a quick win for the project and normally motivates the researchers and the sponsors to have the process completed quickly since the results will be seen early during the project (Morgan and Brenig-Jones, 2012). Although it is tempting to start with process improvements using lean tools, it is of the utmost importance that implementation does not take place at this stage of the project. This is to ensure that baseline estimates taken later in the measure phase must reflect
the historical process that is being studied (Keller, 2010). A detailed process map was developed after spending quality time analysing the process.

5.3 Measurement system analysis (MSA)

After developing a process map, the next step is to ensure that the measurement system is adequate for the data which need to be collected. An adequate data resolution is needed in order to accurately predict process performance both in variable (measurable) and attribute (count) data (Morgan and Brenig-Jones, 2012). Even when the measurement method provides an adequate data resolution and precision, the measurement might be subject to significant error from a number of sources, which may be quantified by MSA (Kalemkarian, 2006). These errors affect the estimates of process capability, inspection standards and process stability which in turn affect measuring tools such as control charts, ultimately leading to the possible loss of revenue (Kalemkarian, 2006).

The following error categories are found in a measurement: bias, stability and linearity.

Bias: this is defined as the estimate of the systematic form of the systematic error in the measurement system (Keller, 2011). Bias is a simple consistent offset in the estimate; it may be corrected through calibration.

Stability: this ensures that the measurement system’s accuracy does not degrade over time, ensuring that the measurement is consistent even after the project is finished (Morgan and Brenig-Jones, 2012).

Linearity: does the measurement system provide the same level of accuracy across its full range of use? If the error is higher for larger measurements, then the estimates of variation in these cases are inflated (Kalemkarian, 2006).

When measurements are taken for a sample or population, the estimates of variation between the samples include both actual variations between the sample units and measurement error (Morgan and Brenig-Jones, 2012). Therefore, it is important to perform the MSA to determine how much of the variation is due to measurement error. A Repeatability and Reproducibility Analysis is a primary tool used to determine whether the MSA is adequate or not (Gygi and Williams, 2012). A repeatability error is associated with the equipment whereas a reproducibility error is associated with the equipment or people (Allen and Laure, 2006). A discrimination ratio, known as distinction of category, is used to estimate the measurement system’s resolution. If the distinction of category is 2, it means
that the measurement system is adequate for attribute analysis only, but if it is 8 or more, then it is more suitable for statistical analysis (Arthur, 2006). MSA principles were followed to ensure the credibility of the data to be collected.

5.3 Cost of poor quality

Cost of poor quality refers to different costs associated with nonconformity to the process specifications. Identifying these costs helps managers to direct improvement activities and to measure their quality management system (Harrington, 1999). In engineering education these costs are associated with a student not passing the subject when he or she should. Cost of poor quality can be classified in the following categories (Harrington, 1999):

- Internal failure costs: costs a company incurs because of the error detected before the output was accepted by the customer’s company. This is the cost incurred because not everyone did the job correctly the first time. An example of this type of cost is to be found in process scrapping and reworking. In engineering education these costs would be associated with a student repeating a subject.

- External failure costs: these are associated with the customer receiving products or services which do not meet the specifications. These costs are incurred when the appraisal techniques fail to detect all errors before the products or services are rendered to the customers. Examples of these costs are warranty costs, complaints handling costs and product or service liability suits. In engineering education these costs could be associated with a loss of government grant opportunities and industry funding opportunities.

- Prevention costs: these are all costs expended to prevent errors from occurring, all costs related to helping an employee to do the job right first time. In financial terms this is not a cost but an investment in the future. In engineering education these costs can be associated with training, tutorials, mentorship and counselling.

- Appraisal costs: these costs arise from already completed outputs and auditing the process to measure conformance to customer requirements, in order to establish criteria and procedures. In other words these are costs expended to determine whether the activity was done right the first time or not. Examples of these costs are quality audits, proof reading of documents and moderation.

5.4 Six Sigma metrics

According to Hargrove and Burge (2002), LSS metrics focus on one or more of the following critical factors: Critical to Quality (CTQ), Critical to Cost (CTC) and Critical to Speed or Delivery (CTD). Keller
(2011) defined CTQ as all factors related to meeting customer specification requirements, CTC as all factors related to work in progress, overheads, delivery, material and labour even when the cost can be passed on to the customer, with CTD being factors related to the timely delivery of the product or service. It is important to remember that metrics must be customer focused, integrated within the business strategy and developed collectively by the researcher and people working where the process is being improved (Pande et al., 2000, Antony and Banuelas, 2002, Gupta, 2005). CTQ, CTC and CTD were determined for the engineering education process after critical observation and analysis of the process.

5.5. Process baseline

The process baseline metric is a single metric which can be used to estimate the current state of the process and its ability to meet customer requirements (Morgan and Brenig-Jones, 2012). The baseline estimate typically consists of the process metric used in operations and accepted within the organisation; for example student throughput rate (Kalemkarian, 2006). The process baseline can be determined using enumerative or analytical statistics. Both process baselines must be measureable and indicate process performance (Keller, 2011). However, the use of analytical statistics is preferred since it can differentiate common variation from special cause variation (Morgan and Brenig-Jones, 2012). In engineering education both enumerative and statistic baselines were used. Student throughput was used as a baseline for this process.

5.6 Sigma level estimates

Sigma level is an indicator of process performance. Defects per million opportunities (DPMO) are calculated by dividing defects with the total unit produced, multiplied by opportunities, whereas the sigma level is determined by comparing the process capability index with Z scores (Kalemkarian, 2006). A comparison of the sigma level with DPMO is as illustrated in Table 5.1. When a process is under control, assuming that special causes have been eliminated from the process baseline, then the process is predictable, and short and long-term defect levels can be estimated (Gupta, 2005, Keller and Pyzdek, 2005). Using the process capability index, the process sigma level can be determined. At this stage of the process, many more data are needed to ensure that the actual process capability index is accurate (Gygi and Williams, 2012). In this study, the sigma level was calculated using equation 5.2.
Table 5.1: Comparison of sigma level and DPMO

<table>
<thead>
<tr>
<th>Sigma Level</th>
<th>DPMO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>691,462</td>
</tr>
<tr>
<td>2.</td>
<td>308,538</td>
</tr>
<tr>
<td>3.</td>
<td>66,807</td>
</tr>
<tr>
<td>4.</td>
<td>6,210</td>
</tr>
<tr>
<td>5.</td>
<td>233</td>
</tr>
<tr>
<td>6.</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Source: (Kalemkarian, 2006))

5.7 Application of the measure phase to engineering education

The tools of the measure phase of the DMAIC problem-solving process were applied to the engineering education process. Details are as depicted below.

5.7.1 Detailed process flow

In the engineering education process, the first step of the said phase is the “as is” process mapping. This process map indicates the process followed by both students and lecturers concurrently, in order for learning to occur as shown in Figure 5.1. This map was developed by the researcher.
Figure 5.1: Student “as is” process map
Figure 5.1 indicates areas where non-value adding steps exist in the process; these are possible waste areas in the system. They are:

- Rework associated with unfavourable student assessment results
- Student repeating the subject
- Student appealing for remarking.

These non-value adding steps must be minimised or eliminated from the system in order to improve process efficiency.

Value enabling process steps identified in this process were:

- Registration
- Enrol for subject
- Receive feedback from assessments
- Predicate marks feedback
- Receive feedback from exam
- Graduation.

Value adding processes identified were:

- Attending lectures
- Student studying or interacting with subject matter
- Writing assessments
- Writing exam.

The detailed process map has validated areas to be focused on when analysing the problem. Students repeating subjects were identified as a non-value adding process by the Pareto analysis. Results were further validated by this process flow map.

The engineering education process requires two concurrent processes working together to achieve the desired results: the students’ learning process and lecturers’ teaching process. The non-value added steps from the lecturer’s point of view were identified from Figure 5.2 which shows the “as is” process for the lecturers.

Value adding processes identified were:

- Lecturer prepares for class
- Lecturer delivers a lecture.

Value enabling processes identified were:
• Facilitates assessments
• Grades assessments
• Provides feedback
• Marks exam
• Calculates exam statistics and submits results.

Non-value adding processes identified were:
• Attending to students’ appeals
• Reassessing students
• Conducting and marking re-exams
• Students drop out.
Figure 5:2: Lecturer “as is” process map
5.7.2 MSA

Data obtained from the institution’s data warehouse Management Information System (MIS) were used to develop the baseline sigma level. For this study, it was assumed that the MIS data were accurate; therefore issues of bias, linearity and stabilities are not focused on. However, due to the MIS data not being in the format required for analysis, an MSA was applied in order to verify that the collected data were sufficiently precise so as to be suitable for statistical purposes (Fairbanks, 2007). There are two types of MSA; the Variable Gage Repeatability and Reproducibility (R&R) and Attribute Gage R&R. Variable Gage R&R was adopted for this research because it is the most suitable for the type of data collected in this study which are variable. The importance of accurate data collection is emphasised since the accuracy of the analysis relies on the accuracy of the collected data: the input determines the output (George, 2003). The first set of data was collected by an expert also referred to as the main researcher and the two data collectors (the second and the third research assistants) used for the data collection were trained on how this data must be collected in order to obtain consistent results. Keller (2011) emphasised that for variable data at least 10 samples or documents must be used, and these samples or documents must be measured three times for the analysis. In this study 10 documents were therefore used and were measured three times. Minitab software was used to analyse the data collected. The results of the MSA are presented in Figure 5.3.

![Gage R&R (ANOVA) for Measure](image)

Figure 5.3: Gage R&R for data collectors
The results drawn from the analysis depicted in Figure 5.3 revealed that there is a minimal contribution due to the RR Part, suggesting that the operators collected data in a uniform manner. The results also revealed that collected data yielded similar readings since the Measure by Operator graph is almost straight. This confirms the view that the operators performed uniformly in terms of reading the data.

The RR Part* Operator Interaction graph shows whether any given data sheet was difficult to read by any particular operator. Figure 5.3 revealed that Document 5 was difficult to read since most data collectors recorded errors with regard to that document. A total of 10 distinctions of category were reported; hence the measurement system was deemed adequate for the variable data. The results of this study indicated that the operators were in good standing concerning the data collection; therefore, they were able to continue collecting data from the MIS and the survey administered to students.

5.7.3 Cost of poor quality

Cost of poor quality was calculated as presented in Table 5.2 using the following categories: internal failure costs, external failure costs, prevention and appraisal costs. The data used were obtained from TUT’s MIS section. The DHET determines the money to be paid to the university based on the enrolment plan and actual number of students enrolled for the last two years. According to the TUT MIS, the total grant which TUT receives from DHET is determined by the Teaching Input Grant (TIG), Teaching Output Grant (TOG), Research Output Grant (ROG) and Institutional Factor Grants (IFG) with allocations of 56%, 14%, 12% and 6% respectively (Mubangizi, 2006) and these allocations differ each year based on the enrolment plan. The portion of the money the university loses or opportunity loss is associated with the Teaching Input Unit (TIU) which is calculated by multiplying the weight of the programme given by the DHET guidelines by the Full Time Equivalent (FTE) which is the full load or full credit a student is expected to obtain at the end of the year. For Engineering, (funding category II) 1 FTE is equal to 2.5 TIU; the DHET paid TUT R10,029.00 for 2011 and R10,499.00 for 2012 per 1 FTE. Therefore, if a student does not take a full load equal to 1 FTE a department loses money. The majority of the students fail at least one subject per semester, which normally has a weight of 0.083 each. Thus, of the total number of students registered for 2011 and 2012, according to the MIS data, only 10% of the headcount are carrying a full subject load. A calculated 90% of the 380 students failed one subject per semester in the Department of Industrial Engineering which, as a consequence, lost R10,403,123.58 for the year 2011 and R10,295,754.05 for 2012 from the TIG. Details of the cost of poor quality are evidenced in Table 5.2 for the abovementioned department for the years 2011 and 2012.
For the TOG, the faculty graduation rate was at 14% for 2011 while the Department of Industrial Engineering undergraduate graduation rate was 9.7%, which translates to 37 graduate students in 2011 and 27 graduate students for 2012, which translates to 5.7%. For 2011, if the graduation rate had been 14% then 54 students would have graduated and in the same way, for 2012, making an assumption of a 14% graduation, 66 students would have graduated. The financial implications of this are shown in Table 5.2.

Table 5.2: Cost of poor quality for the Department of Industrial Engineering

<table>
<thead>
<tr>
<th>Types of Costs</th>
<th>Description</th>
<th>Years</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External Cost</strong></td>
<td>TIG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Credit unit per subject ($a$)</td>
<td></td>
<td>0.083</td>
<td>0.083</td>
</tr>
<tr>
<td></td>
<td>Cost of 1 FTE in Rand Value ($b$)</td>
<td></td>
<td>10,029</td>
<td>10,499.00</td>
</tr>
<tr>
<td></td>
<td>Number of semesters ($c$)</td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Total TIG cost ($a \times b \times c$) in Rand value</td>
<td></td>
<td>1664.81</td>
<td>1742.834</td>
</tr>
<tr>
<td></td>
<td>TOG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Amount of money received from DHET for TOG ($g$)</td>
<td></td>
<td>710 189</td>
<td>533 627</td>
</tr>
<tr>
<td></td>
<td>Number of students graduated ($h$)</td>
<td></td>
<td>37</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>TOU per student ($h/g$)</td>
<td></td>
<td>19194.30</td>
<td>19763.96</td>
</tr>
<tr>
<td></td>
<td>Total External Cost loss (I)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total TIG loss + estimated TOG loss</td>
<td></td>
<td>20859.11</td>
<td>21506.79</td>
</tr>
<tr>
<td><strong>Internal Cost</strong></td>
<td>Operational cost per year ($j$)</td>
<td></td>
<td>257 479.64</td>
<td>196 647.73</td>
</tr>
<tr>
<td></td>
<td>Number of students ($k$)</td>
<td></td>
<td>380</td>
<td>479</td>
</tr>
<tr>
<td></td>
<td>Total internal cost lost per student (II)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operational cost per student per year ($j/k$)</td>
<td></td>
<td>677.58</td>
<td>413.13</td>
</tr>
<tr>
<td><strong>Estimated Appraisal Cost/Student</strong></td>
<td>Estimated appraisal cost per student per year ($e$)</td>
<td></td>
<td>8 381.80</td>
<td>7 684.62</td>
</tr>
<tr>
<td><strong>Estimated Prevention Cost/Student</strong></td>
<td>Estimated prevention cost per student per year ($f$)</td>
<td></td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td><strong>Total Costs Loss/Student</strong></td>
<td>(I)+ (II)+ (III) + (IV)</td>
<td></td>
<td>30418.49</td>
<td>30104.54</td>
</tr>
</tbody>
</table>

5.7.4 Six Sigma metrics

In this research, the throughput rate was used as the baseline metric and the graduation rate as secondary metric. As explained earlier, throughput rate is defined by the DHET as the percentage of the number of students graduating in a year to the number of students in the baseline/cohort (Scott
et al., 2007), while the graduation rate is the number of students in the system divided by the number of students who graduated. The difference between these two measurements is the result of the graduation rate metric not taking into consideration how many years the students stay in the system. The result is therefore distorted because the students might take six years to graduate but they will be counted as if they had graduated within three years. Throughput rate was chosen for this study to be used as the primary metric, even though the university does not generally pay so much attention to this factor as the number of enrolments and graduation rates are used as the basis for funding by the DHET. Throughput data for Industrial Engineering are shown in Figure 5.4. Other secondary metrics are the number of students who drop out as illustrated in Figure 5.5 and the number of excluded students as shown in Figure 5.6. As throughput increases, student dropout and exclusions are supposed to decline; therefore monitoring this metric as a secondary metric was found suitable. The identified metrics which were intended to be improved in this study are directly related to quality as well as cost and delivery, with the aim of making the process better, faster and on time. These were examined in more detail, and are discussed below.

![Throughput rate graph](image)

**Figure 5.4: Primary metric: Throughput rate 2004 to 2007 (Support, 2013)**
Figure 5.5: Secondary metric: Student dropout number (Support, 2013)

Figure 5.6: Secondary metric: Number of students excluded (Support, 2013)
5.7.4.1 CTQ metrics

Unlike a production process, an engineering process does not have actual tangible defects since it is a service process. However, if defects are defined as all students failing a subject, the DPMO is now able to be calculated and used to monitor quality. The following items represent the nomenclature and relationships which were applied in this study with modifications to fit the application thereof to the engineering education process:

- Defects (D): student who fails any subject
- Units (U): the number of students who enrolled for the Industrial Engineering programme.
- Opportunity (O): the number of subjects to be done in the department

A DPMO value of 428,024 was then established, from data of the cohort entering between 2004 and 2010, from equation 5.1:

\[
DPMO = \frac{\text{total number of defects}}{\text{total units} \times \text{opportunities per unit}} \times 10^6 \quad \text{..... (5.1)}
\]

5.7.4.2 CTC metrics

Critical to cost metrics were taken as the cost associated with a student repeating a subject. The cost of failing a subject per student is presented in Table 5.2 which amounts to R30,418.49 for the year 2011 and R30,104.54 for the year 2012. Opportunity loss is calculated by the ratio of FTE and headcount data from the MIS which indicated that 90% of students fail a subject. Using this value, the cost of poor quality for 2011 was R10,403,123.58. This amount is significant but could be drastically reduced, if not completely eliminated, by increasing the quality (the throughput) in the process. It was decided not to use this metric to measure process performance because if the quality was improved then these savings would be realised. Instead, the study focused on improving throughput within the content of each subject, which in turn will increase the graduation rate, resulting in the department being profitable.

5.7.4.3 CTD metrics

It is of the greatest importance that students complete their study within the three year period (minimum completion period if a student is not failing) assigned to them in order to prevent costs associated with repeating subjects. The current average completion period is five years and five months in Industrial Engineering, confirming the national statistics indicating that the majority of such students complete their studies after five years (Scott et al., 2007). In this research CTD is important because, if students stay longer within the programme, they deny places to other students who could have been studying. In addition they lower the throughput rate. Improving the number of students passing the subjects will result in improving costs and years spent in the system.
5.7.5 Process baseline

Using data from the MIS, Figure 5.4 indicates the throughput rate of the Department of Industrial Engineering which was used as the process baseline. The historical data used were taken from students entering the department from 2004 to 2009 and who graduated in three years (in relatively record time). The average throughput rate of the Department of Industrial Engineering was at 14%.

5.7.6 Sigma level

The DPMO value of 428 024 established from data of the cohort entering from 2004 to 2010 was then used to calculate defects per unit (DPU) x 10^-6 which is DPMO. The baseline sigma level of the process using the Poisson distribution, according to Burge III et al. (2004) may be obtained using equation 5.2.

\[ Y = P(x = 0) = \frac{e^{-\mu}}{x!} = e^{-\mu} = e^{DPU} \]  

Here: Yield (Y) – represents the Poisson distribution, which equates to the probability of zero defects; \( \mu \) is the mean of the distribution, \( x \) is the number of failures, D is defects, U is the unit, and DPU is defects per unit.

From data collected by the MIS, the number of defects in the process from 2004 to 2009 is 1 005 and the total number of students (units) is 2 348; consequently the number of defects per unit is 0.43. The probability of obtaining a zero defects (yield) was calculated, using equation 5.2, to be 0.6505. This means there is a probability that 65% of the students will graduate in three years.

The value of DPU obtained was used to estimate the \( Z \) variable equivalent from the normal distribution table and, if a 1.5 shift is factored in, the sigma value can also be calculated using equation 5.3 according to Keller (2011).

\[ \text{Sigma level} = (Z \text{ value}) + 1.5 \]  \( \)  

A DPU value of 0.43 results in a \( z \) value of 0.18 using a normal distribution table, but the sigma level value is 1.68. The sigma level of 1.68 means that the process is not capable, according to Table 5.1.

5.8 Summary

In this chapter “as is” process mapping was explained and developed for the engineering education process. Process metrics were defined, critical to customer satisfaction was discussed, a measurement system was completed and the process baseline was developed. The engineering education process measure phase followed the same characteristics as in a manufacturing environment. However, due to the fact that this is a service process, some relationships were articulated in order to determine the
process sigma level. The Poisson distribution was used since historical data used to determine the sigma level were not variable data. Burge III et al. (2004) used the Poisson distribution to calculate the sigma level. Pande and Holpp (2002) and Keller (2011) showed that the sigma level may be calculated by using the determining process capability index and then converting this to a sigma level with the use of the Z-Table. For this research a Poisson methodology was used because the data available is attributed data and this methodology is more appropriate for sigma level calculations related to such data.

In the following chapter the analyse phase of LSS problem-solving methodology will be discussed and implemented. The objective of the said phase is to determine the value adding process steps, analyse the source of the variation and to determine the process drivers that significantly impact on process output.
Chapter 6: Analyse Phase

6.1 Introduction

The previous chapter outlined how the measure phase of LSS problem-solving methodology may be applied in engineering education processes. In this chapter the focus falls on how the analyse phase may be applied in an educational process. This phase focuses on ensuring that process variation is minimised and that the non-value adding processes are identified and eliminated or minimised. Key variables which impact on the process output were also looked at here. The sources of these process variations were analysed and a cause and effect diagram was developed to narrow down root causes of the identified sources of process variation. By doing so, the resources are able to be focused on variables which will yield significant results should they be improved.

6.2 Analysing sources of variation

Results of the Pareto analysis (Figure 4.2) carried out in the define phase revealed that the main variables affecting student throughput in the Industrial Engineering department and which had been prioritised, were: student subject failure, student dropout, students waiting for WIL I or WIL II and students failing WIL I or WIL II. The source(s) of these variations were analysed using different statistical analysis tools to find the detailed source of the problem and their impact on the process.

6.2.1 Source and types of variation

Depending on the type of data used, the right tool is needed to ensure the identification of causes of variation. Two sources of variation are normally available in each process: special and common causes. The former causes of variation normally occur as a result of an abnormality occurring within a process. Understanding and eliminating this will result in process stability according to Gygi and Williams (2012). Common cause variations cannot be easily associated with the point to point variation because they represent the combination of factors common to all the subgroups (Gygi and Williams, 2012). The source of variation was identified by analysing the data collected on identified potential causes of variation by using the following statistical tools: logistic regression, factor analysis, rolled throughput and network function, hypothesis testing and regression analysis. These tests were carried out to identify, establish and validate the sources of variation.
6.2.2 Data collection on source of variation

Data on source of variation were collected using a well-structured questionnaire in order to investigate aspects affecting the achievements of students during the first two years of study, that is, Semesters 1 to 4. The purposeful sampling method was employed to determine the size of the sample of respondents. This technique allows the selection of the size of the sample of respondents as representatives from a group of respondents who are available and accessible. As previously mentioned, the questionnaire was designed based on literature regarding throughput in engineering education and consisted of two sections: Section A, which dealt with biographical information and Section B, which dealt with factors affecting performance (seven closed questions and one open ended question).

A pilot study was conducted for the purpose of validating the developed questionnaire. A total of 100 questionnaires were administered to students of Industrial Engineering during the 2010 academic session, of which 70 responded while 10 students were also interviewed on potential factors responsible for students failing subjects and dropping out. Feedback from the questionnaire administered and the interviews conducted were used to develop the final questionnaire which comprised 15 closed questions that assessed items contributing to students failing subjects, 18 closed questions which assessed items contributing to students dropping out of the programme or the university and three open-ended questions which assessed contributory factors of the faculty and the department with regard to students dropping out of the programme or the university. (Appendices A to E contain the sample of the questionnaire and the ethics approval letter from TUT.)

Table 6.1 displays factors included in the questionnaire.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Class timetable schedule</td>
<td>9.</td>
<td>Test timetable schedule</td>
</tr>
<tr>
<td>2.</td>
<td>Lack of or inadequate facilities, e.g., laboratories, lecture rooms</td>
<td>10.</td>
<td>Teaching and learning material not clear</td>
</tr>
<tr>
<td>3.</td>
<td>Semester tests difficult</td>
<td>11.</td>
<td>No feedback on class tests or semester tests by lecturers</td>
</tr>
<tr>
<td>4.</td>
<td>No class tests done in class</td>
<td>12.</td>
<td>Lecturer not approachable after class</td>
</tr>
<tr>
<td>5.</td>
<td>Lecturer not available for consultation</td>
<td>13.</td>
<td>Struggle to study</td>
</tr>
<tr>
<td>6.</td>
<td>I did not understand the lecturer</td>
<td>14.</td>
<td>Had a conflict with the lecturer</td>
</tr>
<tr>
<td>7.</td>
<td>Problem with the language</td>
<td>15.</td>
<td>No mentorship</td>
</tr>
<tr>
<td>8.</td>
<td>Not enough time to cover work due to semester courses</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.2.2.1 Participants and procedures
The final questionnaire was administered to 550 students which included: 450 students who were studying in the FoEBE and who were registered for Industrial Engineering and 100 students who were previously registered for Industrial Engineering, but who had dropped out of the university and whose responses were collected telephonically. A total of 424 students who participated voluntarily returned the questionnaire, giving a 77.09% response rate comprising 374 (83.11%) out of 450 questionnaires administered to the first set of students and 50 (50%) out of the second set.

6.2.3 Data analysis and results
SPSS Version 16 was used to analyse the data. The data were cleaned to ensure accuracy prior to starting the analysis and Cronbach’s alpha test was used to test for internal consistency. A cut-off point of 0.7 was considered in this study. Factor analysis was used for data reduction and for grouping items according to factors. Logistic regression analysis was used to predict items that contributed to students failing the subjects and dropping out.

6.2.3.1 Factors related to students’ biographical information
Table 6.2 presents the results on biographical information.

### Table 6.2: Result of biographical information

<table>
<thead>
<tr>
<th>Gender</th>
<th>% Male</th>
<th>% Female</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>69</td>
<td>31</td>
</tr>
<tr>
<td>Age</td>
<td>≤ 17</td>
<td>18-20</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>Provinces</td>
<td>KZN</td>
<td>GP</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>34</td>
</tr>
<tr>
<td>Parents’ Employment Status</td>
<td>Employed</td>
<td>Not employed</td>
</tr>
<tr>
<td></td>
<td>66</td>
<td>29</td>
</tr>
<tr>
<td>Average Income of Parents and Guardians per Annum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 10 000</td>
<td>10 000</td>
<td>51 000</td>
</tr>
<tr>
<td>50 000 - 120 000</td>
<td>180 000 - 240 000</td>
<td>360 000</td>
</tr>
<tr>
<td>24</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>Year of entering TUT</td>
<td>2004</td>
<td>2005</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>
6.2.3.2 Factors related to students passing engineering subjects

Table 6.3 reports results on factors related to students passing engineering subjects.

Table 6.3: Responses related to the level of the subject failed

<table>
<thead>
<tr>
<th>Level of Subject Failed</th>
<th>Frequency</th>
<th>% of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIL I</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>WIL II</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>4th Semester</td>
<td>19</td>
<td>4.55</td>
</tr>
<tr>
<td>3rd Semester</td>
<td>53</td>
<td>12.68</td>
</tr>
<tr>
<td>2nd Semester</td>
<td>162</td>
<td>38.76</td>
</tr>
<tr>
<td>1st Semester</td>
<td>184</td>
<td>44.02</td>
</tr>
<tr>
<td>Total</td>
<td>418</td>
<td>100</td>
</tr>
</tbody>
</table>

For the analysis to be effective a Cronbach’s alpha test was performed to check internal consistency and a result of 0.7785 was reported. A logistic regression test was subsequently conducted in order to determine the factors relating to student achievement. The data indicated that the factors outlined in Table 6.4 have a significant relationship to student achievement. By using a p-value of 0.05 as a cut-off point, the impact on student performance is depicted in Tables 6.4 and 6.5.

Table 6.4: Logistic regression results of factors affecting student achievement

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Results P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Test timetable schedule</td>
<td>0.0016</td>
</tr>
<tr>
<td>2.</td>
<td>Lack of facilities, e.g., laboratories, lecture room</td>
<td>0.0000</td>
</tr>
<tr>
<td>3.</td>
<td>Had a conflict with the lecturer</td>
<td>0.0000</td>
</tr>
<tr>
<td>4.</td>
<td>Problem with the language</td>
<td>0.0003</td>
</tr>
<tr>
<td>5.</td>
<td>No mentorship</td>
<td>0.0058</td>
</tr>
<tr>
<td>6.</td>
<td>Not enough time to cover work due to semester courses</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

Using factor analysis to form the data reduction, three latent constructs emerged. These are presented in Table 6.5. Items that correlate with each other have been pooled together to form a factor.
Table 6.5: Factors that contribute to students failing subjects

<table>
<thead>
<tr>
<th>S/N</th>
<th>Factors</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aspects of academic schedule</td>
<td>Class timetable schedule</td>
</tr>
<tr>
<td></td>
<td>Class timetable schedule</td>
<td>Test timetable schedule</td>
</tr>
<tr>
<td>2</td>
<td>Aspects of adaptation to learning environment</td>
<td>Struggled to study</td>
</tr>
<tr>
<td></td>
<td>Did not understand the lecturer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Teaching and learning material not clear</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Problem with the language</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not enough time to cover work done</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Aspects of teaching and learning</td>
<td>Lack of facilities</td>
</tr>
<tr>
<td></td>
<td>No feedback on tests by lecturer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No mentorship</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No class tests were done in class</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lecturer not approachable after class</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lecturer not available for consultation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Had a conflict with lecturer</td>
<td></td>
</tr>
</tbody>
</table>

6.2.3.3 Factors related to dropout

One of the major factors contributing to low throughput in engineering education is the student dropout rate. The literature clearly indicates that the majority of students who enrolled for engineering programmes dropped out after the first year of study (Araque et al., 2009, Burge III et al., 2004). This stimulated the researcher’s interest in investigating what factors cause TUT Industrial Engineering students to drop out and at which level they do so. Table 6.6 reveals that approximately 60% of the students sampled dropped out of certain courses after their first year of study.

Table 6.6: Level of dropout

<table>
<thead>
<tr>
<th>Level of Dropout</th>
<th>Frequency</th>
<th>% of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIL I</td>
<td>1</td>
<td>2.00</td>
</tr>
<tr>
<td>WIL II</td>
<td>2</td>
<td>4.00</td>
</tr>
<tr>
<td>4th Semester</td>
<td>6</td>
<td>12.00</td>
</tr>
<tr>
<td>3rd Semester</td>
<td>11</td>
<td>22.00</td>
</tr>
<tr>
<td>1st Semester</td>
<td>14</td>
<td>28.00</td>
</tr>
<tr>
<td>2nd Semester</td>
<td>16</td>
<td>32.00</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>100.00</td>
</tr>
</tbody>
</table>
As mentioned, various researchers (Baars, 2009, Charlotte and Lori, 2004, Nariman, 2007) agreed that factors affecting student dropout are complex and sometimes psychological in nature and that they vary from one environment to another. Students were therefore asked to rate the factors (according to Table 6.7) that they believed might have caused their dropping out where after the results were analysed. From the dropout analysis none of the factors showed a P-value of less than 0.05 after logistic regression analysis as reported in Table 6.8, which is an indication that these factors are not the direct causes of dropout.

Table 6.7: Factors used to measure student dropout rate

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Lack of finances</td>
<td>10.</td>
<td>Peer pressure: e.g. pressure from friends, pressure from relationships</td>
</tr>
<tr>
<td>2.</td>
<td>Family pressures: e.g. parents’ ill health, parents pass away, get married</td>
<td>11.</td>
<td>Pregnancy</td>
</tr>
<tr>
<td>3.</td>
<td>Lecturer’s interaction with students in class</td>
<td>12.</td>
<td>Not fitting into the institution’s culture: e.g. involvement in student life activities, adjusting to tertiary life without parents’ supervision</td>
</tr>
<tr>
<td>4.</td>
<td>Lecturer’s interaction with students during consultation</td>
<td>13.</td>
<td>Not coping with the work required</td>
</tr>
<tr>
<td>5.</td>
<td>Lecturer’s presentation of the subject not clear</td>
<td>14.</td>
<td>Conflict with a lecturer</td>
</tr>
<tr>
<td>6.</td>
<td>Time frame of the course too short</td>
<td>15.</td>
<td>Transport problems</td>
</tr>
<tr>
<td>7.</td>
<td>Head of Department interaction with students</td>
<td>16.</td>
<td>Your ill health</td>
</tr>
<tr>
<td>8.</td>
<td>Departmental Administrator's interaction with students</td>
<td>17.</td>
<td>Did not understand the work</td>
</tr>
<tr>
<td>9.</td>
<td>Dean’s office’s interaction with students</td>
<td>18.</td>
<td></td>
</tr>
</tbody>
</table>
Table 6.8: Logistic regression results on factors affecting student dropout rate

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Lack of finances</td>
<td>0.1035</td>
</tr>
<tr>
<td>2.</td>
<td>Family pressures: e.g. parents’ ill health, parents pass away, get married</td>
<td>0.8646</td>
</tr>
<tr>
<td>3.</td>
<td>Lecturer’s interaction with students in class</td>
<td>0.3283</td>
</tr>
<tr>
<td>4.</td>
<td>Lecturer’s interaction with students during consultation</td>
<td>0.2884</td>
</tr>
<tr>
<td>5.</td>
<td>Lecturer’s presentation of the subject not clear</td>
<td>0.5584</td>
</tr>
<tr>
<td>6.</td>
<td>Time frame of the course too short</td>
<td>0.1960</td>
</tr>
<tr>
<td>7.</td>
<td>Head of Department’s interaction with students</td>
<td>0.4117</td>
</tr>
<tr>
<td>8.</td>
<td>Departmental Administrator’s interaction with students</td>
<td>0.4614</td>
</tr>
<tr>
<td>9.</td>
<td>Dean’s office’s interaction with students</td>
<td>0.6614</td>
</tr>
<tr>
<td>10.</td>
<td>Peer pressure: e.g. pressure from friends, pressure from relationships</td>
<td>0.7387</td>
</tr>
<tr>
<td>11.</td>
<td>Pregnancy</td>
<td>0.1259</td>
</tr>
<tr>
<td>12.</td>
<td>Not fitting into the institution’s culture: e.g. involvement in student life activities, adjusting to tertiary life without parents’ supervision</td>
<td>0.2071</td>
</tr>
<tr>
<td>13.</td>
<td>Not coping with the work required</td>
<td>0.8211</td>
</tr>
<tr>
<td>14.</td>
<td>Conflict with a lecturer</td>
<td>0.8702</td>
</tr>
<tr>
<td>15.</td>
<td>Transport problems</td>
<td>0.2279</td>
</tr>
<tr>
<td>16.</td>
<td>Your ill health</td>
<td>0.4689</td>
</tr>
<tr>
<td>17.</td>
<td>Did not understand the work</td>
<td>0.5821</td>
</tr>
</tbody>
</table>

6.2.3.4 Factors related to assistance required

Respondents were also asked to indicate whether they sought help after they failed the subjects or before they dropped out. Only 12 respondents answered this question of which 67% said they had not sought help whereas 33% did do so. Approximately 66% of the respondents indicated that they had requested tutorial support and mentoring before they dropped out of the programme, while 10% indicated that they had requested psychological help as well as assistance from the Head of Department. The students also indicated that they needed more tutoring and mentors to assist them when they struggle with their subject matter.
6.2.4  Determination of source of variation

A bottleneck in any process results in a low throughput rate. For the purpose of this study, “bottleneck” is defined as any part of the process (academic subject) in which the throughput rate is less than the allowable process throughput. In the FoEBE, a subject with a minimum throughput rate of less than 50% is considered as a bottleneck subject. A continuous flow is important in an engineering education process because, as noted, the cycle is longer than that of other industrial processes. Low throughput rates lead to higher dropout rates and delays in graduation. Once the factors affecting throughput had been established, the need to narrow down specifically to the bottleneck subjects became apparent. To do this, the network function and RTY analyses were carried out to identify the subjects with low throughput rates, contributing to significantly low throughput within the department.

6.2.4.1  Network functions

Network functions for the Department of Industrial Engineering were developed by arranging the subjects as per the curriculum structure (Appendix N) and the subjects were linked and controlled by the prerequisite subjects. The network map illustrates the Industrial Engineering National Diploma programme structure and indicates how the subjects are linked to each other through prerequisite subjects. Render et al. (2009) indicated that the network system defines relationships within the system and clarifies how the steps of the process (subjects) follow each other. This network is designed to allow the maximum flow of objects from one area to the next. By observing the Industrial Engineering programme network, it was evident that it was designed to allow students to move easily from one subject to the next, thereby maximising the flow of students from one level to the next provided they pass their registered subjects. Nevertheless, bottlenecks occur, for example, a delay caused by failing one subject means that the student will not be able to enrol for the next level subject unless he or she passes the previous one. If the subject is a prerequisite, a student needs to wait for approximately six months while repeating the failed subject before registering for the next one. The developed network function is as shown in Figure 6.1.
6.2.4.2 RTY calculations

The RTY is defined as a tool to determine the “first time right” performance of a process. Taghizadegan (2006) emphasises that RTY is essential in order to measure process performance accurately and identify process bottlenecks. A process step with a poor RTY generally constitutes a bottleneck station. In order to improve the overall process performance, efforts must be directed to that particular station. Figure 6.2 shows how RTY is calculated in a manufacturing process.
Figure 6.2: RTY calculations in a manufacturing process

Utilising the illustrations in Figure 6.2, equation 6.1 was used to calculate the RTY.

\[ Y = \left( \frac{x_1 - A_1}{x_1} \right) \left( \frac{x_2 - A_2}{x_2} \right) \left( \frac{x_3 - A_3}{x_3} \right) \ldots \text{nth process step} \]  \hspace{1cm} (6.1)

Where:
- \( x_i \) = Units which are inputs to the process step
- \( A_i \) = Units scrapped or reworked at workstation,
- \( i \) = Process step number and
- \( Y \) = Throughput yield of the process or system

It is important to note that reworked outputs still form part of the process outputs; only scrapped outputs are removed from the process immediately.

6.2.4.2.1 Determination of RTY for the subjects

Utilising equation 6.1, the throughput rates illustrated in Figure 6.3 were calculated for the subjects based on 2007 to 2009 data.
6.2.4.2.2 Determination of the programme rolled throughput rate for the class that entered TUT in 2007 and finished in 2009

From Figure 6.3 the programme RTY was determined using equation 6.1. To calculate this RTY, the subject with the lowest throughput rate was identified and utilised to calculate for the overall system. Since there are prerequisites for certain subjects and the students who fail these are unable to register for subjects at a higher level, the subjects with the lowest throughput associated with a semester are used to calculate the programme throughputs, which are: PHY101T; MAT241T; QAS201T and ORS301T. This was done for all the semesters to determine the programme RTY to be 6.2% as shown in equation 6.2.

\[
Y_p = PHY101T \times MAT241T \times QAS201T \times ORS301T
\]

\[
= 0.40 \times 0.50 \times 0.35 \times 0.60 = 6.2 \%
\]  

(6.2)

The 6.2% indicates that the rolled throughput rate for the system is dismal. Nevertheless, the subjects that should be targeted, on which resources should be spent, have been identified in the process. The
network structure in Figure 6.3 was divided into sub-processes, bottleneck subjects were identified per sub-process as indicated in Figure 6.3. Ten sub-processes were identified and their RTY were calculated using equation 6.1 to determine the critical paths of the system. Six of these ten paths were critical with RTYs of 19, 22, 28, 35, 39 and 40%; see Table 6.9 for the details. The rolled throughput rate of the subjects mentioned, for the period 2007 to 2010, was compiled. The result is recorded in Table 6.10.

Table 6.9: Determination of critical path

<table>
<thead>
<tr>
<th>Path No</th>
<th>Description</th>
<th>RTY in %</th>
<th>Critical Path Yes or No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>( \text{Min} (0.68 \times 0.70 \times 0.50 \times 0.71 \times 0.80) )</td>
<td>28</td>
<td>Yes</td>
</tr>
<tr>
<td>2.</td>
<td>0.56 \times 0.50 \times 0.79</td>
<td>22</td>
<td>Yes</td>
</tr>
<tr>
<td>3.</td>
<td>0.77</td>
<td>77</td>
<td>No</td>
</tr>
<tr>
<td>4.</td>
<td>0.78 \times 0.65 \times 0.77</td>
<td>39</td>
<td>Yes</td>
</tr>
<tr>
<td>5.</td>
<td>0.78 \times 0.92 \times 0.80</td>
<td>57</td>
<td>No</td>
</tr>
<tr>
<td>6.</td>
<td>0.74 \times 0.78 \times 0.60</td>
<td>35</td>
<td>Yes</td>
</tr>
<tr>
<td>7.</td>
<td>0.71</td>
<td>71</td>
<td>No</td>
</tr>
<tr>
<td>8.</td>
<td>0.86 \times 0.80</td>
<td>69</td>
<td>No</td>
</tr>
<tr>
<td>9.</td>
<td>0.54 \times 0.35 \times 0.80</td>
<td>19</td>
<td>Yes</td>
</tr>
<tr>
<td>10.</td>
<td>0.40</td>
<td>40%</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 6.10: Rolled throughput rate and sigma level from 2007 to 2010 for some subjects

<table>
<thead>
<tr>
<th>Year</th>
<th>Subject</th>
<th>Rolled Throughput Rate</th>
<th>Sigma Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>PHY101T</td>
<td>0.40</td>
<td>1.25</td>
</tr>
<tr>
<td>2008</td>
<td>PHY101T</td>
<td>0.52</td>
<td>1.57</td>
</tr>
<tr>
<td>2009</td>
<td>PHY101T</td>
<td>0.37</td>
<td>1.15</td>
</tr>
<tr>
<td>2010</td>
<td>PHY101T</td>
<td>0.51</td>
<td>1.55</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>0.45</td>
<td>1.37</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Subject</th>
<th>Rolled Throughput Rate</th>
<th>Sigma Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>MRD101T</td>
<td>0.5</td>
<td>1.50</td>
</tr>
<tr>
<td>2008</td>
<td>MRD101T</td>
<td>0.61</td>
<td>1.74</td>
</tr>
<tr>
<td>2009</td>
<td>MRD101T</td>
<td>0.71</td>
<td>2.05</td>
</tr>
<tr>
<td>2010</td>
<td>MRD101T</td>
<td>0.64</td>
<td>1.85</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>0.62</td>
<td>1.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Subject</th>
<th>Rolled Throughput Rate</th>
<th>Sigma Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>MAT241T</td>
<td>0.50</td>
<td>1.50</td>
</tr>
</tbody>
</table>
### 6.2.4.3 Further analysis on the identified subject with the lowest rolled throughput rate

QAS201T was identified as the subject with the lowest average rolled throughput rate of 43 (seen in Table 6.10) on the critical path of the network function (Figure 6.3). There was therefore a need to further investigate the root cause of this low performance because increasing the rolled throughput of this subject might in turn increase the general rolled throughput. To achieve this, the sources of process variation and process drivers within the QAS201T class were determined. This was done by applying lean tools like 7 waste and 5S. For this study 7 waste was used to bring the process to stability, starting with overproduction, meaning producing more than needed for a class from the lecturers’ perspective, or what they do not need, from the students’ perspective (Arthur, 2006). Either way, time and resources would be wasted and this might result in a student failing the subject. The following issue of waste is over-processing. This was evident, particularly from the lecturers’ perspective. Sometimes lecturers spoon-feed students to the extent that the latter do not know how to collect and make sense of information by themselves. Waiting is another of the wastes experienced: this was as a result of some lecturers going over their time in a session with students resulting in students waiting for venues for classes and laboratories. Motion waste was also evident, although this was due to the design of classrooms and the space problems encountered by the faculty. Students have to move from...
one classroom to the next and this wasted an estimated 75 minutes a day, which is a lot of time which they could use for group work and other activities.

Transport waste is associated with travelling from one area to the other. It was also identified that most of the students spend an average of three hours per day commuting from their residential areas to the university. This placed a strain on them, resulting in them sleeping during the session and missing the core concepts discussed in class. Correction waste is related to time spent correcting errors, marking scripts and attending to students as a result of students repeating the subject which they should have passed. This waste would be associated with scrapping and reworking in a manufacturing setup.

Inventory waste is the waste related to students spending extra time in the system by repeating the subjects. These students fill the classrooms resulting in new students trying to enrol for the subjects not getting a place. If this waste in the process is minimised or eliminated, the quality of teaching and learning should improve, thereby increasing the throughput of the department. Data as to how much waste was eliminated from this process were not collected since it was too complex to gather this from all students in the system. In order to determine the root cause of this phenomenon, a focus group of QAS201T students was formed to analyse why students fail their subjects. An additional focus group of lecturers from the Industrial Engineering department was formed to work together to determine why students were failing QAS201T. The cause and effect diagram was developed to identify potential $X$ which impacts on the $Y$. Arthur (2006) and Fairbanks (2007) assert that in order to develop an effective cause and effect analysis, a “5 why” analysis must be performed. With this method, the question “why” things are happening the way they are happening must be asked five times in order to determine the root cause of the problem. Using Figure 6.4, five causes of students failing the subjects or alternatively dropping out of the programme were identified as: not prepared for test or exam; struggle to study; learning material not clear; students cannot get year marks and a language barrier. After a brainstorming session, potential causes of variation were rated; the items with high ratings were listed and subjected to further analysis to determine if they were indeed the causes significantly affecting the output of the process.
Since this method is not quantitative but qualitative and the potential causes identified were related to the outcome of the survey presented in Table 6.4. Subsequently, the brainstorming session, which is less scientific than a survey, confirmed that students not prepared for tests and struggling to study are the potential causes of them failing the subjects. There was a need to validate this scientifically, hence the need for hypothesis testing which provides the opportunity to determine if there is actually a significant difference between a sub-group with potential causes and a sub-group without such causes.

**Hypothesis testing**

In LSS, data must be collected on the potential causes of failure and statistical analysis must be performed to validate the cause(s) before solutions are developed. The next step of this analyse phase is to collect data on the potential causes and analyse them accordingly. For instance, students not being prepared for tests as a cause of their failing them: the TUT requirements stipulate that students need to attain a mark of at least 50% in order to pass that particular test. Normally, written tests weigh more than tutorials and assignments, since this is the only way to test a student’s cognition level for that particular subject matter. In order to test this cause, students’ performances were sampled: the data collected clearly indicated that students who fail tests but somehow gain examination entrance, fail the examination. Hence, this particular phenomenon was verified as a cause. Students struggling to study were identified as the second cause of student subject failure. Historically, students are required to study teaching and learning material in the form of textbooks, modules and notes in order
to pass their assessments. Failure to study in most cases leads to students failing the subject. In order for the team to test this cause, a sample was chosen from students to test the following hypothesis:
A: students who studied
B: students who did not do so

The hypothesis statement was as follows: the performance of students who study is equal to the performance of students who do not study their course material.

H₀: Mean Test results A = Mean of test results B
H₁: Mean Test results A ≠ Mean of test results B

The data were subjected to a normality test to determine their normality. The results are depicted in Figures 6.5 (a) and (b). From Figure 6.5 (a), the test indicates that the data is not normal; however, for test two (Figure 6.5(b)), the data is normal; therefore it was used for the analysis. Two sample T-tests to determine equity of means between two sub-groups were also carried out. A two sample T-test was utilised for this study because it is suitable to test the equality of means of two sub-groups. The results are presented in Figures 6.6 (a) and (b) and Table 6.11.

![Figure 6.5: Normality test result (a: Sub-group Test 1; b: Sub-group Test 2)](image)

![Figure 6.6: Result of two sample T-tests (a: Box Plot; b: Individual Value Plot)](image)
Table 6.11: Result of two sample T-tests

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Standard Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test results 1</td>
<td>53</td>
<td>18.9</td>
<td>22.8</td>
<td>3.1</td>
</tr>
<tr>
<td>Test results 2</td>
<td>53</td>
<td>59.1</td>
<td>10.3</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Other results from the two samples T-tests are as listed below:

i. Estimate for difference: -40.19

ii. 95% CI for difference: (-47.00, -33.37)

iii. t-Test of difference = 0 (vs. not =):

iv. t-Value = -11.70

v. p-Value = 0.000

vi. Degree of Freedom, DF = 104.

The p-value of p = 0.000 is less than 0.05; therefore the null hypothesis was rejected, which signifies that the test results of students who did study are not equal to the test results of the students who did not. The results verify that students need time to study in order for them to pass tests or exams.

To further understand the current situation, the amount of time per week students spend studying the subject called Quality Assurance 2 (QAS201T) when they write a semester test or during a semester test week, and after the semester test week, was determined. In this regard, hypothesis testing was performed utilising two sample T-tests. The hypothesis statements are:

The time spent studying the subject QAS201T during a test week is equal to time spent studying QAS201T during a normal lecturing week.

H₀: Mean time spent studying during test week = Mean time spent studying during normal classes.

H₁: Mean time spent studying during test week ≠ Mean time spent studying during normal classes.

Two sample t-tests to determine equity of means between the two sub-groups were also carried out; the results are presented in Figures 6.7 (a) and (b) and Table 6.12.
Figure 6.7 (a) and (b): Results of two sample T-tests on time spent studying QAS201T (a: Individual Value Plots; b: Box Plots)

Table 6.12: Result of two sample T-tests on time spent studying QAS201T

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Standard Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test results 1</td>
<td>32</td>
<td>38.4</td>
<td>59.1</td>
<td>10</td>
</tr>
<tr>
<td>Test results 2</td>
<td>32</td>
<td>91.3</td>
<td>72.9</td>
<td>13</td>
</tr>
</tbody>
</table>

Other results from the two sample T-tests on time spent studying are as listed below:

i. Estimate for difference: -52.8
ii. 95% CI for difference: (-86.0, -19.6)
iii. t-Test of difference = 0 (vs not =)
iv. t-Value = -3.18
v. p-Value = 0.002
vi. Degree of Freedom (DF) = 59.

The p-value for this study is 0.002, which is less than 0.05; therefore the null hypothesis is rejected and the alternative hypothesis is accepted. The results indicate that the average time students spend on QAS201T during normal classes is less than the average time they spend studying this subject during a test week, which indicates that on average, students spend 38 minutes studying QAS201T per week as opposed to 91 minutes during a test week.
6.3. Application of network function and RTY calculation to other related departments

Some Industrial Engineering subjects are similar to those of Mechanical and Electrical Engineering. As the students have common subjects in the first semester of both programmes, it was important to determine these two departments’ RTY and whether there is a possible opportunity for improvements. The outcome was that the methodology could also be adopted by other departments to determine their bottleneck subjects. Should they identify these subjects and focus resources on them, the overall throughput rate of the faculty should improve since the various departments’ throughput has a direct relationship with the overall faculty throughput.

6.3.1 Mechanical Engineering programme

The Mechanical Engineering programme has the same structure as that of Industrial Engineering: two years of theoretical subjects and one year of practical, although students studying Mechanical Engineering can choose to either specialise in Mechatronics or the Manufacturing programme. Figure 6.8 indicates the Mechanical Engineering programme structure. The network flow of the Mechanical Engineering department indicates a slightly more convoluted flow than that of Industrial Engineering. This type of flow gives rise to bottlenecks since, if a student fails a subject that is a prerequisite, he/she cannot proceed to the next level subject. There are three main flows in Mechanical Engineering: the Mechanics flow, Mathematics combined with Strength of Material and the Design flow. This means that if a student is experiencing difficulties in any of these streams, they will not be able to proceed and they tend to either change their course or drop out. Figure 6.8 depicts the network function of the Mechanical Engineering programme while Figure 6.9 presents the network function of Mechanical Engineering with rolled throughput analysis developed using equation 6.1.

Subjects with a throughput of less than 50% were again considered bottleneck subjects. In the Mechanical Engineering programme, there are eight subjects which have an average RTY of 50% as depicted in Table 6.13.
Figure 6.8: Mechanical Engineering network (refer to Appendix O)
Figure 6.9: Mechanical Engineering with rolled throughput data

Table 6.13: Mechanical Engineering subjects with throughput of less than 50%

<table>
<thead>
<tr>
<th>Subject Codes</th>
<th>Average Throughput Rate</th>
<th>Sigma Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>EET101T</td>
<td>46</td>
<td>1.39</td>
</tr>
<tr>
<td>MMH211T</td>
<td>44</td>
<td>1.35</td>
</tr>
<tr>
<td>MMH311T</td>
<td>44</td>
<td>1.35</td>
</tr>
<tr>
<td>TMH301T</td>
<td>44</td>
<td>1.35</td>
</tr>
<tr>
<td>MAT171T</td>
<td>47</td>
<td>1.41</td>
</tr>
<tr>
<td>SMT331T</td>
<td>47</td>
<td>1.41</td>
</tr>
<tr>
<td>ASA301T</td>
<td>45</td>
<td>1.37</td>
</tr>
<tr>
<td>MAT271T</td>
<td>49</td>
<td>1.47</td>
</tr>
</tbody>
</table>
6.3.2 Electrical Engineering programme

The Electrical Engineering programme structure has a more straightforward flow than either the Mechanical or Industrial Engineering programmes. The network indicates five critical paths: electrical engineering, mathematics, electronics, digital systems and a project. Similar to the Mechanical and Industrial courses, if students cannot pass some subjects in this flow, they have to change to another programme, drop out or be excluded. One element which Electrical Engineering contains, unlike that of Mechanical and Industrial Engineering, is project work as a separate subject, spread over three semesters. Electrical engineering also has many areas of specialisation, from light current to clinical engineering, therefore giving students many options to choose from. The detail of the Electrical Engineering programme structure is graphically represented in Figure 6.10. The network shows a smooth flow from one semester to the next. The programme is well streamlined and although the structure was developed for all possible programmes in Electrical Engineering, students may choose the critical flow they need to follow for them to specialise in a particular field.

Figure 6.10: Electrical Engineering programme network (refer to Appendix P)
The rolled throughput data were calculated using equation 6.1 and Figure 6.2. The results are illustrated in Figure 6.10 depicting the Electrical Engineering programme network and Figure 6.11 which illustrates the Electrical Engineering programme with throughput data. The network indicated that the worst bottleneck subjects are Software Design II (SFD 201T) and Electronics III (ELC331T). This is of concern because these subjects’ throughput rates are indicated as being at 39% and 36% respectively. Other subjects which are below the 50% cut-off point are indicated in Table 6.14.

**Table 6.14: Electrical Engineering subjects with a throughput of less than 50%**

<table>
<thead>
<tr>
<th>Subject Code</th>
<th>Throughput Rate</th>
<th>Sigma Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAT171T</td>
<td>48</td>
<td>1.44</td>
</tr>
<tr>
<td>ESL111T</td>
<td>48</td>
<td>1.44</td>
</tr>
<tr>
<td>ELC211T</td>
<td>40</td>
<td>1.25</td>
</tr>
<tr>
<td>SFD201T</td>
<td>39</td>
<td>1.23</td>
</tr>
<tr>
<td>ELC331T</td>
<td>36</td>
<td>1.15</td>
</tr>
</tbody>
</table>
6.4. Identified common areas of focus for the three departments

Table 6.15 presents the identified common subjects with low throughput rates after the analysis of the three programmes. These subjects are common problem areas across the departments requiring joint interventions in order to improve their throughput.

**Table 6.15: Identified common subjects with a low throughput**

<table>
<thead>
<tr>
<th>Subject Code</th>
<th>Name of the Subject</th>
<th>Level of the Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETT101T</td>
<td>Electro Technology 1</td>
<td>Semester 1</td>
</tr>
<tr>
<td>MAT171T</td>
<td>Mathematics I</td>
<td>Semester 1</td>
</tr>
<tr>
<td>MAT271T</td>
<td>Mathematics II</td>
<td>Semester 2</td>
</tr>
<tr>
<td>MHC101T</td>
<td>Mechanics I</td>
<td>Semester 1</td>
</tr>
<tr>
<td>DSY231T</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DYT30YT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSY341T</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.5 Summary

In this chapter, the analyse phase of DMAIC problem-solving methodology was outlined. The sources of variation were analysed to obtain the details of the root causes of the problem; their impacts on the process were also determined. To achieve these, data on the source of variation were collected and analysed. The results of the analysis were presented in figures and tables. Tools used to analyse sources of variation were discussed and a process of determining key variables was described. Some of these tools were applied to the problems investigated in engineering education. As engineering education is a transactional process and is complex because of the combined effect of the student and
lecturer relationship, some tools were not applicable, such as value stream mapping. The applicable tools used in this phase were the RTY and the network function. These were utilised to narrow down specific subjects for individual departments to focus on. This also applied to those departments that share these same subjects with Industrial Engineering.

Now that the key variable which affects the throughput rate in QAS201T has been identified, the next chapter concentrates on remedying the situation. The chapter considers what may be done to improve the throughput of this subject. The improve phase of the DMAIC problem-solving methodology focuses on establishing a permanent improvement process which will result in customer satisfaction and organisational benefits. Innovation and team-work is necessary for this phase to be successful. In some cases a DOE or simulation is used to predict future process performance.
Chapter 7: Improve Phase

7.1 Introduction

The previous chapter explored the analyse phase. Tools used in this phase were discussed as well as their application. This chapter considers the determination of new process operating conditions. This is usually achieved by incorporating innovative ideas but sometimes by trial and error. Process improvements are implemented, monitored and verified. Benefits associated with these improvements are estimated and verified. In some cases, failures associated with a new process are investigated and addressed. The engineering education process flow was redefined, while simulation was used to determine variations which are subtle yet which affect the system. This was important in that, as has been indicated, the engineering education process is a lengthy one. The implications of the duration of the study are that when introducing any change, simulations are required to determine its impact or to evaluate if the change in the variable will cause a significant change in throughput. In a manufacturing process, this could have been done by designing experiments, but in an engineering education process simulation is the best method.

7.2 Development of a new process for the Engineering Higher Education System

According to Keller (2011), in a DMAIC problem-solving methodology, the outcome of the improve phase produces a new process definition which will replace the current operating procedure. Detailed process mapping and value stream mapping indicate process steps which are non-value adding processes, yet which are potential improvement areas. If these processes are minimised or eliminated, process steps or procedures will have to change. Tools such as brainstorming sessions, benchmarking and innovation processes are useful in designing a new process flow. Understanding systems engineering enables new concepts of integrated elements within the system to be imagined; therefore the new process will not disturb the flow of other connected processes (Richmond, 2004). While redefining the process flow, data of the process output must still be collected and statistical analysis carried out to confirm positive changes when process variables are altered. In most cases tools such as regression analysis, hypothesis testing and design of experiments, simulation and process control charts are used to monitor process changes (Arthur, 2006). In this improve phase, diverse tools such as those mentioned above, including simulation, brainstorming sessions, benchmarking, innovation
processes and process control charts were used because of the nature of the system under consideration.

7.2.1 Simulation

Process models determined by experimentation or process design, may be useful in simulation since this enables finding optimal solutions for the problem, particularly when the problem is complex in nature and encompasses many variables which affect each other (Ferrin and Muthler, 2002, Khan, 2013). Simulation provides a means of using probability estimates for the random variables to discover the impact of their joint probabilities (Khan, 2013).

Experimentation is a valid but expensive tool and the cycle duration of some processes is too long; by the time the experiment is completed, variables of the process may have already changed (Khan, 2013). Simulation also allows more situations for testing than is practically possible with experimentation, which makes it suitable for “what if” analysis and for testing the response in worst case scenarios too (Keller and Pyzdek, 2005).

Ferrin and Muthler (2002) and Keller (2011) list the uses of simulation as: verifying analytical solutions; studying dynamics situations; determining significant components and variables in a complex system; determining the variable’s interactions; studying effects of change without risk, cost and time of experimentation and teaching. Studies by Bubevski (2010) and Ferrin and Muthler (2002) (Bubevski, 2010, Ferrin and Muthler, 2002) indicated that simulation may be used in Six Sigma to model key system variables which may make it costly to develop an experimental design of a real process. Although Six Sigma has not been used with system dynamics simulation, Keller and Pyzdek (2005) reported that simulation may be used to study a dynamic situation. Engineering education throughput is a dynamic problem, and since it changes over time, system dynamics modelling is an appropriate modelling tool. Most system dynamics work related to improving efficiency has been done for education at primary and secondary level, but not in higher education (Terlou et al., 1991, Pedamallu et al., 2012, Altamirano and Daalen, 2004).

7.2.1.1 System dynamics principles and methodology

System dynamics models are usually formulated as systems of high order, nonlinear, possibly Stochastic differential equations portraying the decision rules of the agents, natural processes, and physical structures relevant to the purpose of the model (Forrester, 1994). All non-trivial models will be of this high order and include so many nonlinearities that no analytic solutions are known and the equations are solved by numerical methods. What distinguishes system dynamics models from many
other dynamic models is not the mathematics, but the specification of the equations and the modelling process, the fact that in system dynamics one can model both mathematical and non-mathematical components in one model. The models often include discrete elements, queuing structures and individual agents, depending on the purpose. Dynamics models utilise a broad model boundary. There should be few exogenous variables since the model focuses on endogenous variable and connectivity of variables with the feedback loops. The specification of models should not be compromised to achieve analytic tractability, although simplification and linearisation are often helpful in understanding the behaviour of the full model.

Statistical methods for parameter estimation should be used where possible and are helpful, but good models include all variables thought to be important, whether numerical data to estimate the parameters are available or not. Omitting such so-called soft variables is less scientific and less accurate than using best judgment to estimate their values (Forrester, 1994). To omit such variables is equivalent to saying they have zero effect, probably the only value that is known to be wrong (Forrester, 1994). Models should be grounded in and tested against the widest array of data, including numerical data, archival information and qualitative data gathered from interviews, observation and other ethnographic methods. The rate equations capturing the decision rules of the agents must be based only on information known to be available, capture delays and distortions introduced by measurement, reporting systems, perception processes and administrative procedures (Forrester, 1994).

Models must be robust under extreme conditions and conform to the basic laws of physics, for example, production in the model of a firm cannot proceed without labour, operation equipment, materials and energy; shipments must be zero when the finished inventory is zero. These principles may seem to be nothing more than common sense as it is obvious that people cannot use information they do not have and that physical impossibilities are, in fact, impossible. Yet many models routinely violate these principles. Forrester says: “Economists routinely assume people have perfect information about the customer preferences and production possibilities, perfect knowledge of the future and the ability to predict how others would behave in hypothetical situations: information that real people perceive through a fog, if at all”. System dynamics also addresses the root causes that allow errors to go undetected and uncorrected. Graphical user interfaces enable modellers to quickly capture the feedbacks, stocks and flows, time delays and nonlinearities they identify (John, 2000). Equations can be written using friendly algebra so that advanced mathematical training is no longer necessary.
Sensitivity analysis, optimisation and parameter estimation can be largely automated. A model is easily converted into an interactive flight simulator with an intuitive interface. Yet, while the software becomes ever easier to use, modelling is not computer programming. Better software does not replace thinking. Tools for learning about complexity must also facilitate the process of systems thinking and policy design. While simulations enable controlled experimentation, they do not require the application of the principles of scientific method. Researchers’ inquiry skills often reinforce rather than correct their biases and judgmental errors. Confirmation and hindsight bias, defensive routines and groupthink can thwart learning from models just as they do in the real system. Effective modelling often requires members of the client team to recognise the limitations of their inquiry skills and address their own defensive behaviours. People unaccustomed to disciplined scientific reasoning and an open, trusting environment with learning as its goal will have to acquire and hone these basic skills before a system dynamics model or, indeed, any model can prove useful. Developing these skills takes effort and practice (Forrester, 1994).

7.2.1.2 Procedure involved in applying a system dynamics model

In this phase of the LSS problem-solving method, the system dynamics model was adopted to simulate the proffered solution to the identified and validated problems of the throughput rate in higher education learning from other phases of the LSS. The procedure involved in applying a system dynamics model to simulate a complex system is as stated below (John, 2000):

i. Problem formulation
   This is one of the fundamental steps in system dynamics modelling. According to John (2000) the following questions must be asked when formulating the problem: What is the issue to be solved? What is the real problem? What is the purpose of the model? The purpose is to assist in ensuring that only items of content within the purpose are considered while those outside the scope are removed from the model. Its usefulness lies in the fact that it represents reality; therefore it is important that the model accurately and clearly represents the problem to be solved.

ii. Time horizon
   The time horizon should reflect the historical behaviour of the system as well as its current state of performance. It must also extend far enough into the future to capture the delay and the effect of such delays on the situation being studied. It is important to understand that the
effects are normally felt only after a long period of time, hence, extending the time framework will enable the model to capture realistic information as required.

iii. Dynamic hypothesis
The dynamic hypothesis must be formulated after the problem and time horizon have been determined. This hypothesis is a working theory of how the problem arose and is dynamic because it must provide an explanation of the dynamics characterising the problem in terms of the underlying feedback, stock and flow structure of the system. When developing a model, an endogenous explanation for the problematic dynamics must be offered (John, 2000).

iv. Development of causal loops
Causal loops are flexible and useful tools to represent how variables are related and feedback structures affect any domain. They clearly indicate the causal links amongst variables with directional links from a cause to an effect. It is important to develop these loops before the model is devised to ensure that all possible variables of the relationship are outlined.

v. Model development
A conceptual model must first be advanced before the actual simulation is developed. This helps the model developer to think systematically about the system and the dynamic hypothesis. Once a conceptual model is devised, the simulation model can be built. This aids in the process of recognising vague concepts and of resolving contradictions that had gone unnoticed during the conceptual phase. The use of stocks and flows is important in order to model the system appropriately. Stock represents the accumulation of activities whereas flows represent items and activities flowing from one stock to the other. Flows are rates of increase and decrease in stocks; hence adjusting these will affect the stock.

vi. Generate result
Results are generated as a result of testing the model. Testing begins as soon as equations are put in the system. Generating results enables one to compare the simulated behaviour with the actual system behaviour. Every model must correspond to a meaningful concept of the real world and equations must be checked for dimensional consistency to ensure mathematical validity. Sensitivity analysis model behaviour and recommendations must be assessed in the light of uncertainty about assumptions.

vii. Analyse result
Once the results are generated and the sensitivity analysis is performed, results may be analysed and conclusions drawn from the results. In some cases results may be different from those anticipated. Testing equations and the adjustment of parameters must therefore be
carried out to ensure that the model did capture all variables in the real world system. Graphical and tabular representations can be used to explain the results.

viii. Adjust parameters and reiterate
In most cases, the model parameters will have to be adjusted and further testing must be undertaken to validate the system behaviour. New strategies, structures and decision rules might be utilised in order to design and test certain policies or variables. This will enable further enhancement of the model to ensure that suitable structures are developed in order to represent the system appropriately. Sensitivity analysis must be redone to test the robustness of the variables and ensure that the effects of feedback loops are considered and accounted for.

ix. Discussion and conclusion
Once the tests and results are satisfactory, discussions can take place and conclusions may be drawn from the model. Policy implications may be communicated and adopted as per the requirements (John, 2000).

7.2.2. Implementing the solution
After the desired solution has been determined by innovation, brainstorming or simulation, the solution should be implemented (Gupta, 2005). It is important to obtain the necessary approval of process changes from the sponsor and process owner before implementing such changes (Pande and Holpp, 2002). Results of the analysis serve as justification why a process should be changed and why the new process is efficient and able to meet customers’ needs (Arthur, 2006). The next step is then to redefine the new operating conditions of the process. This procedure must consist of optimal solutions developed from the design of experiments or simulations and tested to ensure that the new processes will not result in more problems than the current processes cause (Ferrin and Muthler, 2002, Khan, 2013). Arthur (2006) advises that these process changes must be implemented in phases to allow personnel to be trained and to become competent in new ways of doing things. While process change must be managed to ensure efficiency, it is important to gain a buy-in from all personnel affected by the changes before even attempting implementation (Allen and Laure, 2006, Antony and Banuelas, 2002). A new process must take into consideration issues such as ergonomics, process waste and potential failure modes (Yang et al., 2011, Moore, 2007). This must be integrated into the new process and it must also be ensured that the necessary resources are available for employees to perform the task effectively.
Assessing benefits of the proposed solution is important. Gupta (2005) and Morgan and Brenig-Jones (2012) propose a cost-benefit analysis using financial tools such as breakeven point analysis, net present value and return on investment. Although not all these tools might be used at the same time, depending on the nature of the solution proposed, sometimes the said solution requires a financial investment and management will therefore want to know if the organisation will benefit from the investment. A matrix of the proposed solution and its associated cost-benefit analysis should be developed before a feasible solution for the organisation is chosen (Morgan and Brenig-Jones, 2012). In a situation where the solution is clear, available and part of the organisational system, the cost-benefit analysis is not necessary since there will be no need for additional investment in order to implement the solution (Arthur, 2006). Communication to the team, management, sponsor, process owner and employee must always be provided to ensure constant buy-in of employees into the new process.

7.3 Application of improve phase to the engineering education throughput project

The analyse phase indicated that subject failure is one of the key variables which impacts on faculty throughput. The use of RTY and network function identified subjects which should be focused on in order to achieve a significant improvement in the overall throughput rate.

In this phase, a system dynamics model was developed for the whole Engineering Higher Education System with the purpose of modelling key variables such as: entry level student quality, student quality, staff quality, staff to student ratio, financial exclusion, academic exclusion, voluntary exclusion, impact of time spent studying and learning environment. The subject identified with the lowest throughput rate for the Industrial Engineering department was a subset of the engineering higher education system: QAS201T. This therefore was the first on which to focus the improvement strategy. Cause and effect diagrams and hypothesis testing indicated that the key variable affecting students’ progress in this subject was lack of time to prepare for the class, tests and ultimately the exam, due to the large volume of work in this particular subject and other compulsory subjects. These variables or key policies were modelled and the effects of causal loops were outlined. Variables were tested to observe how the model would behave when certain parameters were adjusted. The results were presented in figures and tables.

7.3.1 Simulation of engineering higher education system using system dynamics model

In system dynamics, in order for the model to represent the desired system to be modelled, a problem statement/formulation, time horizon, a dynamic hypothesis and causal loops are developed before
modelling starts. After the modelling, results are generated and analysed. The parameters are adjusted and the iteration continues until an optimal solution is achieved. Thereafter results are discussed and conclusions drawn.

### 7.3.1.1 Problem formulation

The throughput rate for the TUT FoEBE for the last five years has been stable at an average of 14%. This model seeks to vary the identified key variables or policies which have a major impact on throughput, to obtain an optimal point so that actions and controls may be placed on those variables, which should result in an increased throughput rate.

### 7.3.1.2 Time horizon

As previously pointed out, the engineering education process is a long term one. Therefore, for the model to show a true variation it must be modelled over a long period. Generally, in the engineering education process, curricular changes take place after a decade. Modelling a process for longer will reveal the impact of policy changes and other variables over that period. Another aspect is the fact that it takes about six years for one cohort of students to go through the process. Consequently a longer time horizon is suitable for this simulation. Based on these points, a time horizon of 40 years was used from 2010 to 2050 to give a clear picture of the impact of policies (variables) over a long period of time.

### 7.3.1.3 Dynamic hypothesis

Over a period of time, throughput will decrease as a result of increase in enrolment numbers, students not being funded and students not engaging in their studies, which will ultimately lead to poor throughput rates. As has been stated, for the purpose of this study throughput refers to students graduating after three years of study. The model was thus built to represent a three year programme and not a six year one. This hypothesis assumes that there is a causal relationship between all these variables that affect throughput in the system and output or graduation.

### 7.3.1.4 Causal loop

A thorough analysis of the causal loop was undertaken to describe key variables impacting on throughput, as outlined by John (2000). There are three causal relationships in this loop as depicted in Figure 7.1. The first is between passing/promotion, graduation, students in the system and current student quality. The loop illustrates that passing leads to graduation, which in turn reduces the number of students in the system, which impacts on current student quality. The second loop is between passing/promotion, graduation, carrying capacity, number admitted, student in the system
and current student quality. Once again passing leads to graduation which in turn increases carrying capacity. This will determine the number of students to be admitted which likewise determines current student quality. The last loop outlines the relationship between passing/promotion, graduation, carrying capacity, desired enrolment, number admitted, students in the system and current student quality.

Figure 7:1: Feedback loop of the variables

7.3.1.5 Model development

Policies impacting on the hypothesis were used to develop the model, represented by the use of stocks and flow, enabling the testing of different policies on the hypothesis and determining the results. The initial model developed represented the aging chain model of the Engineering Higher Education System, while the final model developed represents the effects of varying the key variables on the system.
7.3.1.5.1 Initial model development

As explained earlier, the engineering higher education process of TUT generally comprises two years of theory and one year of practical studies. In order to study at TUT, students need to apply. If the application is accepted (meeting the requirements), the students need to enrol at the university at the beginning of the semester after which they register as a student of TUT.

Students can move from one level to the other if they pass their subjects. If they do not pass their subjects, they can repeat them. If they fail again and do not meet the university exclusion policy rules (Appendix Q), they are excluded. This TUT engineering higher education structure is common to the entire engineering diploma programme in all UoTs in South Africa. This procedure is thus considered as representative of the Engineering Higher Education System.

The main stocks and flows factor for this model is the aging chain, representing the flow of students from first year to graduation. This relationship and variables affecting university throughput are represented by sub-models with the feedback loops in Figure 7.2 illustrating the initial system dynamics throughput model. Using the average pass rate and dropout rate as the indicators of the flow, the model shows how the students flow through the system.

Throughput determinants

The central part of this model outlines how students flow from one semester to the next and how factors such as dropout and success rate impact on this flow. The rates used for dropout differ from semester to semester as per the average data from the university system. For the sake of simplicity, the semester model was depicted, indicating how students enter the university, go through classes, are promoted to the next semester or not at the end of the semester, and how dropout occurs during the year and at the end of it.

Pass rate

The concept of a pass rate is a complex phenomenon. Due to variations affecting the engineering process, it is almost impossible to predict student performance, let alone average student performance, according to Schwartz and Washington (2002). In this study, for the initial model pass rate, values were taken from the faculty data which report averages of 30%, 60%, 60%, 70%, 70%, 16.99% from Semester 1 to Semester 6 respectively, because this represents weighted value which is an accurate representation of average student performance.
Students entering the system were determined using equation 7.1 while equation 7.2 was used to determine the number of students that pass from one semester to another:

\[ \text{semester}_1 \text{ students}(t) = \text{semester}_1 \text{ students}(t - \delta t) + (\text{new 1st years} - \text{pass 1st to 2nd} - \text{dropout 1st semester})\delta t \] \hspace{1cm} (7.1)

\[ \text{pass 1st to 2nd semester} = (\text{semester}_1 \text{ students} \times \text{pass rate 1st to 2nd}) \] \hspace{1cm} (7.2)

**Dropout**

Dropout is represented by the dropout rate which consists of the data from the cohort analysis. The following dropout rate data from the said analysis was used for the initial model development: 0.33, 0.21, 0.22, 0.12, 0.07 and 0.1 from Semester 1 to Semester 6 respectively. The number of students dropping out was determined using equation 7.3:

\[ \text{semester dropout} = \text{semester students} \times \text{dropout rate} \] \hspace{1cm} (7.3)

**Graduation**

The number of graduating students is determined using equation 7.4 while the number of students who graduated (Alum) is determined using equation 7.5:

\[ \text{Graduating} = \text{Semester 6 Students} \times \text{graduating rate} \] \hspace{1cm} (7.4)

\[ \text{Alum}(t) = \text{Alum}(t - \delta t) + (\text{graduating})\delta t \] \hspace{1cm} (7.5)

![Figure 7.2: Initial system dynamic throughput model](image-url)
7.3.1.5.2 Results of initial model developed

The number of students graduating three years after entering the university is depicted in Figure 7.3. It is clear that the numbers will increase from 2010 until they reach a maximum in 2040 where 750 students are graduating annually from 11 000 students in the system, as indicated in Figure 7.4.

Currently, in engineering higher education, about 1 500 students per year are graduating after five years in the system and there are approximately 10 500 students in the faculty. Therefore the results of this initial model are close enough to use for this prediction.

Figure 7:3: Graph of graduating students

Figure 7:4: Graph of students in the system
7.3.1.5.3 Sensitivity analysis of the result of initial model developed

The model baseline and a sensitivity analysis are utilised to test the model when the number of students in the system from 3 000 to 6 000 and 9 000 respectively, as indicated in Figure 7.5. While more students are admitted into the system and numbers graduating increase from year 2010 to 2025, after 2025 the number of graduate remain constant. The graph shows that there is an increase of graduating students as a result of increasing student’s numbers; however this must be done in consideration of the faculty resource capacity.

Figure 7.5: Sensitivity analysis with enrolments of 3 000, 6 000 and 9 000 respectively

7.3.1.5.4 Validity of findings

The model needed to be validated to ensure that the results are realistic and decisions can be made based on this model. John (2000) advised that model validation must be done by comparing the model results with the actual system results, ensuring that mathematical and scientific aspects of the process are accounted for. In this model, validation was done by comparing the results of the model with the actual system results. The faculty enrols 10 500 students each year on average and graduates about 19% each year after they had been in the system for an average of five years. The model indicated that 11 000 students will be admitted and about 7% of the students will graduate within three years. The model was therefore deemed valid for our proposed intervention.

Although this model was validated, it was clear that other variables are still unknown. The question was: Why is the model predicting a total of only 7% graduates after three years? What are the key variables affecting student graduation in record time? The results of the initial model also clearly
demonstrate that increasing student numbers will only increase the throughput to a certain level. Over time, the throughput will be constant if student numbers continually increase until a saturation point, where numbers will remain constant and the throughput will decrease. In order to identify key variables in the system that could lead to increase in throughput, a detailed model was developed. Developing it would provide an answer to the second part of the dynamic hypothesis which seeks to identify the causal relationships within key variables and test the impact of certain policies on the system, should they be adjusted.

7.3.1.5.5 Detail model development for the engineering higher education system

In order to achieve optimal solutions for an increase in the throughput rate, a detailed model was developed to consider all variables in the system that may affect the throughput rate, to identify causal relationships within key variables and test the impact of these variables on the system by adjusting them. This was done by modelling factors that impact on students’ performance in each semester. Since Semesters 2, 3 and 4 are similar, they were modelled using the same variables as were Semesters 5 and 6. Semester 1, however, contained different variables.

Modelling of semesters

Modelling of Semester 1

In order to model students in Semester 1, although the focus of this study is not on enrolment, the means through which students enter the institution had to be taken into consideration. Enrolment in this study is determined by two factors: the faculty’s carrying capacity (the maximum number of students which the faculty is able to enrol) and the desired enrolment (determined by the national DHET as the numbers of students the faculty must enrol annually). The turn-up rate of admitted students determines the number of students in the first semester. Equation 7.6 indicates how students in the first semester are enrolled, while equation 7.7 was used to estimate the number of new first year students entering the system; equations 7.8 and 7.9 indicate how they flow out to the next level within the system:

\[
semester1\ students(t) = semester1\ students(t \ - \ \delta t) + (new\ 1st\ years \ - \ pass\ 1st\ to\ 2nd\ - \ drop\ 1st\ semester)\delta t \quad \ldots \ldots \ (7.6)
\]

\[
New\ 1st\ year\ students = (number\ admitted \times turnout\ rate) \quad \ldots \ldots \ (7.7)
\]

\[
Dropout\ 1st\ semester\ students = semester\ 1\ students \times dropout\ rate \quad \ldots \ldots \ (7.8)
\]

\[
Pass\ 1st\ to\ 2nd = Pass\ rate\ 1st\ to\ 2nd \times semester\ 1\ students \quad \ldots \ldots \ (7.9)
\]
Modelling of Semester 2

Students in Semester 2 follow the same flows as Semester 1 students. However, those in Semester 2 do not arrive in terms of the admission and turn-up rates. Therefore, the students flow into Semester 2 as a result of passing Semester 1 and flow out of Semester 2 when they pass or drop out. Equation 7.10 indicates how the number of students in Semester 2 is determined. Equation 7.11 was used to estimate the rate of flow from Semesters 1 to 2 while equations 7.12 and 7.13 indicate the dropout rate and flow from Semesters 2 to 3 within the system. The situation in Semester 2 applies to Semesters 3 and 4; hence, the same equations were used to determine the number of students, rate of flow from one semester to another and dropout rate:

\[
semester2 \text{ students}(t) = semester2 \text{ students}(t - \delta t) + \text{pass 1st to 2nd} - \text{pass 2nd to 3rd} - \text{dropout 2nd semester})\delta t \ldots \ldots
\]  

(7.10)

\[
\text{Pass 1st to 2nd students} = \text{Pass rate 1st to 2nd} \times semester1 \text{ students} \ldots \ldots
\]  

(7.11)

\[
\text{Dropout 2nd semester students} = semester2 \text{ students} \times \text{dropout rate semester 2} \ldots \ldots
\]  

(7.12)

\[
\text{Pass 2nd to 3rd} = Semester2 \text{ students} \times \text{pass rate 2nd to 3rd} \ldots \ldots
\]  

(7.13)

Semesters 5 and 6 (WIL)

In Semesters 5 and 6 students have left to do WIL I and II in industry. Therefore these semesters differ from the others. Students flow in and out of Semester 5 as a result of passing Semester 4 and of students dropping out. For Semester 6, students flow in and out (some graduating) as a result of passing Semester 5 or dropping out. It should be noted that most of the activities which take place during Semester 5 and 6 are external to the institution. Fewer policies can therefore be employed to make changes. Equation 7.14 indicates how the number of students in Semester 5 was determined, whereas equation 7.15 was used to estimate the rate of flow from Semester 4 to 5 and equations 7.16 and 7.17 indicate the rate of dropout in Semester 5 and flow from Semester 5 to 6 within the system. Equation 7.18 indicates how the number of students in Semester 6 was determined and equation 7.19 was used to estimate the rate of flow from Semester 5 to 6, while equations 7.20 and 7.21 indicate the dropout rate in Semester 6 and students graduating from the system:
\textit{semester 5 students}(t)
\[\text{semester 5 students}(t) = \text{semester 5 students}(t - \delta t) + (\text{pass 4th to 5th} - \text{pass 5th to 6th} - \text{dropout 5th semester})\delta t \ldots \ldots (7.14)\]

\text{Pass 4th to 5th students} = \text{Pass rate 4th to 5th} \times \text{semester 4 students} \ldots \ldots (7.15)

\text{Dropout 5th semester students} = \text{semester 5 students} \times \text{dropout rate semester 5} \ldots \ldots (7.16)

\text{Pass 5th to 6th} = \text{Semester 5 students} \times \text{pass rate 5th to 6th} \ldots \ldots (7.17)

\text{semester 6 students}(t)
\[\text{semester 6 students}(t) = \text{semester 6 students}(t - \delta t) + (\text{pass 5th to 6th} - \text{graduating} - \text{dropout 6th semester})\delta t \ldots \ldots (7.18)\]

\text{Pass 5th to 6th students} = \text{Pass rate 5th to 6th} \times \text{semester 5 students} \ldots \ldots (7.19)

\text{Dropout 6th semester students} = \text{semester 6 students} \times \text{dropout rate semester 6} \ldots (7.20)

\text{Graduating students} = \text{semester 6 students} \times \text{graduation rate} \ldots \ldots (7.21)

\textbf{Factoring in of the variables into the developed model}

There are two main flows in the system: students passing and students dropping out. The student success (pass) rate is affected by many factors such as: new students’ quality, current students’ quality, students’ learning environment, impact of time spent studying on students’ performance, staff to student ratio and staff quality. The students’ dropping out is affected by factors such as: academic exclusion, financial exclusion and voluntary exclusion. Enrolment is determined by turn-up rate and number admitted. The number of students admitted is determined by the university’s carrying capacity, desired enrolment and students currently enrolled. These students are then added into the total number of students in the system. The details of these variables are explained below:

\textbf{Pass Rate}

The model to determine the pass rate for each semester is as shown in equations 7.22 to 7.26:

\textit{Pass rate 1st to 2nd semester} = (1 - \text{impact time spent studying } s_1) \times \text{maximum pass rate } s_1 \times \text{student learning environment } s_1 \times \text{current student quality } s_1 \times \text{new student quality} \ldots \ldots (7.22)
Pass rate 2nd to 3rd semester = \((1 - \text{impact time spent studying } s_2) \times \text{maximum pass rate } s_2 \times \text{student learning environment } s_2 \times \text{current student quality } s_2 \ldots \) \hspace{1cm} (7.23)

Pass rate 3rd to 4th semester = \((1 - \text{impact time spent studying } s_3) \times \text{maximum pass rate } s_3 \times \text{student learning environment } s_3 \times \text{current student quality } s_3 \ldots \) \hspace{1cm} (7.24)

Pass rate 4th to 5th semester = \((1 - \text{impact time spent studying } s_4) \times \text{maximum pass rate } s_4 \times \text{student learning environment } s_4 \times \text{current student quality } s_4 \ldots \) \hspace{1cm} (7.25)

Pass rate 5th to 6th semester = \((\text{Maximum pass rate } s_5 \times \text{current student quality } s_4 \ldots \) \hspace{1cm} (7.26)

Details of how these variables impact on the pass rate were determined and reported as shown below:

**New students’ quality**

At TUT new Students’ quality is primarily determined by the Academic Potential Score (APS). Two categories of students are admitted, those who qualify for the Main programmes and those who qualify for the Foundation programmes. The faculty’s admission criteria states that students with a National Senior Certificate with at least 50% for English, at least 60% for Mathematics and Physical Science with total APS score of at least 28 will be considered for main programmes and that students with at least 50% for English and Mathematic, with at least 40% for Physical Science and a total APS score of at least 20 will be considered for Foundation programmes. This criteria was develop based on a longitudinal study by Van Wyk et al 2014, which indicate that students who obtain 60% for Mathematics and 60% for Science have a at least 50% chance of completing their programmes in engineering fields. The study by Van Der Flier, 2003 agreed with Van Wyk’s findings, indicating that for students to succeed at the university, they must have passed high school Mathematics with at least 60% and Science with 60%, achieving a total APS of 28.
New student quality is also affected by the demand and supply of grade 12 graduates. If the numbers of students preselected to study at FEBE are low compared to the needs of the faculty, then faculty is forced to take more students in the Foundation stream in order to fill the quota. If the numbers are high, then the faculty has enough applicants to choose the best from. Equation 7.27 represents this relationship.

If APS score and grade 12 students’ preselected numbers are used to determine student quality impact, the following analogy can be used: If a student has combined scores of 10 for Mathematics and Physical Science with at least a total APS score of 28 then the quality index is set at 0.5. The better the scores, the higher is the quality index. This relationship was used to determine the graphical function values in Table 7.1.

\[
\text{New student quality} = \frac{\text{Graph}(\text{number of quality high school graduates applying to TUT})}{\text{number admitted}}
\] ......7.27

**Table 7.1: Data used to generate the graphical function to determine new student quality**

<table>
<thead>
<tr>
<th>Number of Quality High School Graduates/Number Admitted</th>
<th>New Student Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.20</td>
<td>0.16</td>
</tr>
<tr>
<td>0.28</td>
<td>0.20</td>
</tr>
<tr>
<td>0.36</td>
<td>0.26</td>
</tr>
<tr>
<td>0.44</td>
<td>0.30</td>
</tr>
<tr>
<td>0.52</td>
<td>0.41</td>
</tr>
<tr>
<td>0.60</td>
<td>0.48</td>
</tr>
<tr>
<td>0.68</td>
<td>0.55</td>
</tr>
<tr>
<td>0.76</td>
<td>0.68</td>
</tr>
<tr>
<td>0.84</td>
<td>0.72</td>
</tr>
<tr>
<td>0.92</td>
<td>0.84</td>
</tr>
<tr>
<td>1.00</td>
<td>0.90</td>
</tr>
</tbody>
</table>

**Current students’ quality**

Current student quality is determined by the quality of the students already in the system and the quality of new students entering the program. For students in semester 1, current student quality is determined by the quality of repeating students and new students from Grade 12. For students at
other levels, current student quality is primarily determined by the quality of students in the system and the quality of students repeating that semester. The larger the group of repeating students, the poorer is the quality of students in that level.

The percentage of subjects passed after one year of study is a powerful predictor of academic success during subsequent years. Therefore the larger the repeating cohort, the poorer is the quality of students in the system. In the FEBE at TUT the correlation between percentage of subjects passed after year 1 and student performance during subsequent years is 0.72 with a significant \( p \) value of less than 0.001. These results were used to develop a relationship between number of repeating student and current student quality. As the number of repeating students grow, the number of students in the system increase and the current student quality decrease. If students pass all the subjects enrolled for, the number of repeaters decreases and the number of students in the system decrease, resulting in an increase in current student quality.

The graphical function was implemented using equation 7.28 and the data in Table 7.2.

Current student quality =

\[
\text{Graph} \left( \frac{\text{Semester 1 students}}{\text{number of students in the system}} \right) \ldots. \tag{7.28}
\]

<table>
<thead>
<tr>
<th>Semester 1 Students/Number of Students in the System</th>
<th>Current Students’ Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40</td>
<td>1.080</td>
</tr>
<tr>
<td>0.60</td>
<td>1.080</td>
</tr>
<tr>
<td>0.80</td>
<td>1.050</td>
</tr>
<tr>
<td>1.00</td>
<td>1.000</td>
</tr>
<tr>
<td>1.20</td>
<td>0.796</td>
</tr>
<tr>
<td>1.40</td>
<td>0.621</td>
</tr>
<tr>
<td>1.60</td>
<td>0.430</td>
</tr>
<tr>
<td>1.80</td>
<td>0.302</td>
</tr>
<tr>
<td>2.00</td>
<td>0.214</td>
</tr>
<tr>
<td>2.20</td>
<td>0.122</td>
</tr>
<tr>
<td>2.40</td>
<td>0.070</td>
</tr>
</tbody>
</table>

**Impact of time spent studying**

The impact of time spent studying demonstrates a relationship with passing the subject matter. It clearly indicates that the more the students are occupied in the classroom, not having personal time, the less time will they have to engage with their work which in turn will result in subject failure. The
study conducted by Kanakana et al. (2012) indicated that time spent studying had a significant impact on students’ achievement. A study by Springer et al. (1999) validated this finding. They indicated that the more time students spent engaging with their work, the more the positive attitude toward the subjects increased resulting in a confident student, which enabled the students to achieve better results. The relationship between contact time with lecturers and time left for students to engage with the work themselves is critical. Amenkhienan (2004) indicated that it is important for students to get time to engage with each other and the lecturer before and after the lecturing session. Hence, time management is critical for students. The more the students study, the higher their chances of passing. The ratio of average self-study time in hours per week to contact hours per week (time spent in classroom) is the impact of time spent studying which is determined by the graphical function using equation 7.29 and Table 7.3 as validated by Kanakana et al. (2012) and Baars (2009a):

\[
\text{Impact of time spent studying} = \text{Graph}\left(\frac{\text{Average self study hours per week}}{\text{Contact hours per week}}\right) \ldots \quad (7.29)
\]

**Table 7.3: Data used to generate the graphical function to determine the impact of time spent studying**

<table>
<thead>
<tr>
<th>Average Self-study Hours per Week/Contact Hours per Week</th>
<th>Impact of Time Spent Studying</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>0.6140</td>
</tr>
<tr>
<td>0.200</td>
<td>0.4770</td>
</tr>
<tr>
<td>0.400</td>
<td>0.3690</td>
</tr>
<tr>
<td>0.600</td>
<td>0.2570</td>
</tr>
<tr>
<td>0.800</td>
<td>0.1980</td>
</tr>
<tr>
<td>1.000</td>
<td>0.1520</td>
</tr>
<tr>
<td>1.200</td>
<td>0.1020</td>
</tr>
<tr>
<td>1.400</td>
<td>0.0713</td>
</tr>
<tr>
<td>1.600</td>
<td>0.0496</td>
</tr>
<tr>
<td>1.800</td>
<td>0.0124</td>
</tr>
<tr>
<td>2.000</td>
<td>0.0062</td>
</tr>
</tbody>
</table>

**Student learning environment**

As noted earlier, the relationship between learning environmental factors is complex. Some of the variables are not dynamic, hence, constant numbers were used such as classroom environment and
living environment (Wohlgemuth et al., 2007). Those variables which are dynamic were investigated further. Two dynamic variables, staff to student ratio and staff quality as in equation 7.30, were used to determine the student learning environment variable:

\[
\text{student learning environment} = \text{Class room environment} \times \text{living environment} \times \text{staff quality} \times \text{impact of staff student ratio} \ldots \ldots \quad (7.30)
\]

**Impact of staff to student ratio**

The impact of this ratio staff to student is critical, since large class sizes might not be conducive to student - lecturer interaction and engagement, especially if traditional teaching methodologies are used. A study by Mills and Treagust (2003) suggests that an appropriate teacher student ratio should be 1:45 in developed countries. In South Africa the average lecturer to student FTE ratio should be 1 : 27 according to CHE data (Scott et al., 2007). It is, however, not always possible and in some cases classes at TUT have up to 600 students. On average the lecturer to student FTE ratio at the TUT engineering faculty is 1:50 (Beer, 2009). The impact of the lecturer to student ratio contributes to the students’ learning environment because when this changes, student performance is affected. Figure 7.6 indicates program’s success rate and number of students registered. This graph indicates that programs with high numbers of students have the least success rate. A study by Springer et al. (1999) validates that learning in small groups has a high impact on student achievement, persistence and attitude amongst the engineering students. They further indicated that the effect of small group learning can move a student from the 50th percentile to the 70th percentile. For the model analysis, this was used as a baseline for the graphical equation. In this model, the preferred ratio is 1:40, therefore the impact of staff to student ratio increases when the actual student to staff ratio increases. Equation 7.31 depicts this relationship while Table 7.4 reports the data used for the graphical function:
Figure 7.6: Faculty success rate and student head count numbers

Impact of staff student ratio = Graph (staff student ratio)...... (7.31)

Table 7.4: Data used to generate the graphical function to determine the impact of the staff to student ratio

<table>
<thead>
<tr>
<th>Staff to Student Ratio</th>
<th>Impact of Staff to Student Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>0.618</td>
</tr>
<tr>
<td>0.005</td>
<td>0.690</td>
</tr>
<tr>
<td>0.010</td>
<td>0.748</td>
</tr>
<tr>
<td>0.015</td>
<td>0.808</td>
</tr>
<tr>
<td>0.020</td>
<td>0.848</td>
</tr>
<tr>
<td>0.025</td>
<td>0.888</td>
</tr>
<tr>
<td>0.030</td>
<td>0.928</td>
</tr>
<tr>
<td>0.035</td>
<td>0.952</td>
</tr>
<tr>
<td>0.040</td>
<td>0.980</td>
</tr>
<tr>
<td>0.045</td>
<td>0.988</td>
</tr>
<tr>
<td>0.050</td>
<td>0.995</td>
</tr>
</tbody>
</table>
**Staff quality**

Staff quality is one of the most important and complex variables. Many factors determine quality, from varying years of experience to the use of different methods of teaching and assessing the students; the quality of the learning material and how the lecturer engages the student in and after class. The model by Basson et al. (2012) identified aspects which may be used to measure staff quality. Some of the variables used include the use of active learning tools like myTUTor, engaging students in class and giving feedback to students (Basson et al., 2012). For the purpose of this study, staff quality impacts the learning environment directly; hence, if it is low, then the pass rate of that particular subject, faculty or university will be low. Equation 7.32 is chosen to model this relationship.

\[
\text{Staff quality} = \text{Use of myTUTor \times use of summative assessment \times years of experience} \quad (7.32)
\]

**Dropout rate**

Three significant factors affecting the dropout rate as identified earlier were studied. As this policy was deemed to be of interest in this model, equation 7.33 calculated this relationship while details of how these variables impact on dropout rates were determined and reported as shown below:

\[
\text{Dropout rate} = \text{Academic exclusion rate} + \text{Financial exclusion rate} + \text{Voluntary exclusion rate} \quad (7.33)
\]

**Academic exclusion**

According to the MIS, about 15% of the student dropout rate each year resulted from academic exclusion due to poor performance, recalling that TUT policy lays down minimum performance requirements for students not to be excluded (Support, 2013). Equation 7.34 was used to determine the academic exclusion rate in the system, which, as mentioned, is a function of impact of time spent studying.

\[
\text{Academic exclusion rate} = \text{Impact of time spent studying} \times 0.5 \quad (7.34)
\]

**Financial exclusion**

On the issue of student funding, TUT students are predominantly impoverished, as established by the findings of the survey indicating that about 70% of students studying at TUT are from poor families, resulting in the majority of them dropping out. The rate of financial exclusion was determined by the
proportion of students relying on financial assistance within the FoEBE, of which according to the MIS, the baseline is 23.2%. Using equation 7.35:

\[
\text{Financial exclusion rate} = \frac{\text{Students in need of financial help} - \text{Number of students funded}}{\text{Number of students in the system}}
\] (7.35)

Voluntary dropout

Voluntary dropout was also studied. However, due to the uncertainty of this variable the decision was made to keep it a constant. As the model progressed from Semester 1 to 2 and towards graduation, the same framework was followed. Different values were used to represent current performance in each semester. In Semester 5 and 6, variables were not included since the students are off campus for WIL.

7.3.1.5.6 Detailed model results

The results of the detailed model were presented in various figures. The sensitivity analysis results after varying the parameters were also presented in figures showing the effect on the number of graduates in a particular year. Figure 7.7 illustrates the complete model for the National Diploma in Engineering Higher Education Process (Appendix H to M). Figures 7.8 and 7.9 indicate the number of students who graduated and number of students in the system respectively, without varying any factors. The following factors were varied and their results were likewise presented in figures: funding policy, academic exclusion policy versus impact of time spent studying, learning environment versus staff to student ratio, learning environment versus staff quality and a combination of all the factors. Details of the results are indicated in Figures 7.10 to 7.16 which will be discussed next.
Figure 7.7 Snapshot of the detailed model
Result of varying funding policy

Funding is one of the important factors impacting on students’ performance. At TUT, 45.3% of students rely on NSFAS funding as per the MIS data, thus indicating that they come from
disadvantaged families and their parents cannot afford to pay for their studies. This affects their performance since the institution has a policy that if students’ funds are not paid, they cannot progress to the next level which puts a strain on their performance (Oyo et al., 2008b). The funding policy was varied by increasing the ratio of students who do not need funding by 70%, 80% and 90%, while other variables were kept constant and a sensitivity analysis was performed to determine the effect on the number of graduates. The result is as depicted in Figure 7.10.

![Figure 7:10: Sensitivity analysis of increase in students who do not require funding (1, 2 and 3 represent 70%, 80% and 90% respectively)](image)

Varying impact on time spent studying

In the analyse phase, time for studying or the time during which students are engaged in their work was identified as a main variable affecting student performance. This variable was simulated along with academic exclusion by varying its parameters to discover their impact on each other. If the researcher keeps all other variables constant and alters the hours students are engaged in the class in a week from 20 to 30 and ultimately to 40 hours, the graduation rate increases as shown in the sensitivity analysis result in Figure 7.11.
Varying staff to student ratio

The said ratio is also one of the important variables in this model. It is an established fact that if the given ratio is too high, student engagement might be compromised leading to poor quality results. To test this variable, all other factors of the model remained constant and a sensitivity analysis test was performed on a number of staff. This test was designed to indicate if there would be an increase in graduation numbers should the staff profile increase. Sensitivity analysis was performed on the increased number of academic staff at 60, 90 and 120. The result is recorded in Figure 7.12.

Figure 7:12: Result of sensitivity analysis of impact of staff on throughput (1, 2 & 3 represent 60, 90 & 120 staff increases, respectively)
Varying lecturer quality

Lecturer quality is one of the main determinants of students’ performance. In fact, in engineering education, academic staff are given the responsibility to manage themselves with little or no supervision (Oliver, 2001) and are trusted with this responsibility, with the only tool being the students’ evaluation reports at the end of the semester to measure lecturers’ performance.

Basson et al. (2012) conducted a study on how to measure lecturer quality. They argued that based on the way a lecturer interacts and engages with the student, one can measure his/her quality. From his study the following variables were taken as the main criteria for measuring staff quality: years of experience in teaching (assuming that the minimum qualification requirement is in place); use of summative and formative assessments in class; and the use of myTUTor in the classroom. The result was interesting and testing this theory in this research model was appealing. Initially, staff quality was placed at 1 as a constant. However, in order to measure the effect of staff quality on throughput, a sensitivity analysis was done, the results of which are presented in Figure 7.13 using 100%, 90% and 80% staff quality.

![Figure 7:13: Result of sensitivity analysis on staff quality (1, 2 & 3 represent 100%, 90% & 80% respectively)](image)

Having been able to test these variables individually, it was clear that some feedback loop activities can be created if certain combined variables are simulated; therefore, the following ones were tested.
Varying combined variables

The proportions of students who do not require funding were increased by 0.70, 0.80 and 0.90 and the time students spent engaged in their studies was increased to 20 hrs, 30 hrs and 40 hrs with staff quality at 80%. Figure 7.14 records the results of this sensitivity analysis.

Figure 7:14: Result of sensitivity analysis of the combined variables (1 represents the combination of 20 hrs, 0.70 & 80%; 2 represents that of 30 hrs, 0.80 & 80% and 3 represents that of 40 hrs, 0.90 & 80%)

7.3.2 Application of optimal solutions to improve throughput rate of identified bottleneck subjects

The optimal solutions arrived at during the simulation stage of the improve phase, after considering all the factors that together impact on throughput rate, were applied to the initially identified bottleneck subjects in the analyse phase in Industrial Engineering (see Table 6.9), Mechanical Engineering (see Table 6.10) and Electrical Engineering (see Table 6.11). The optimal solution relates to variations in combination of: time spent studying, funding and staff quality. Interventions implemented as regards the three departments were: change of timetable, introduction of e-learning (myTUTor) and a new network function was developed, using 2012 data. Detailed results are presented in the figures below.
7.3.2.1 Industrial Engineering department

The identified bottleneck subjects in Industrial Engineering were considered one after the other during the implementation, starting with QAS201T, which is the subject with the lowest throughput rate.

**QAS201T**

The first factor considered under the intervention implemented to improve the throughput rate of this subject was increasing the time spent studying, identified as one of the most critical factors impacting on throughput rate.

The intervention implemented for students failing this subject was to increase the students’ engagement in it, in particular, during the time when there is no test week. This was carried out by increasing the number of class tests and the amount of group work organised for the students. Doing the former, forces students to study before they come to class which in turn makes them ask questions when they do not understand the work. This approach concurs with the line of thought taken by Baars (2009b). Group work, on the other hand, assists students to learn from each other, compelling them to engage with the subject material in their own time. In addition, e-learning was introduced for this subject as suggested by Nora and Snyder (2008) and Hendrik and Serfontein (2004). All the learning materials were placed online for students to access whenever they wished to do so. This helped students to gain access to the work done in class and obtain up-to-date information on the subject matter, even outside the class. The introduction of e-assessments, in particular, was effective because it also obliged them to test their understanding of the work covered. After the implementation of the measures mentioned, the results displayed in Figures 7.15 and 7.16 were reported.

![Box plot for before and after improvements](image-url)
The second variable outlined by the simulation model as a key variable is student funding. This, according to Doolen and Long (2007) is one of the levers which determines whether a student will stay or leave the university. Student funding, however, in the FoEBe is an external factor since the faculty has no influence as the funds come from the university structure and very little can be done to influence this variable. The suggestion on how to improve this situation is in twofold: the faculty only admits students with bursaries and students who have proof that their parents will be able to pay their fees or else the faculty admits students for whom they will solicit bursaries from industry. The former would be problematic since enrolment numbers would be affected by that strategy. The only way is for the faculty to look for a third stream of income which can generate funding for the students.

In order for this improvement to be implemented, resources need to be allocated from the Dean’s office and the university management as such. Although this has merit and significant potential, it could not be immediately implemented at the university.

The last variable considered in improving a learning environment was the lecturer to student ratio. It was suggested that due to the high cost involved in hiring more lecturers, which is controlled by the University management structure and DHET, it is more efficacious for current lecturers to use technological tools to aid learning, as suggested by Hendrik and Serfontein (2004).
These tools will free their time in terms of contact hours, although students will still be able to engage with a lecturer in their own time using media aids. This solution was found to be viable because equipment and support were available as the faculty as a whole when moving towards an e-learning strategy. Although this equipment had not been utilised by the academic staff before this intervention, it was recommended that all lecturers should start employing e-learning materials such as PowerPoint, myTUTor and Blackboard applications for formative and summative assessments and audio visuals. This would enable the students to engage with lecturers working in their own time and any time they want to. This solution was deemed appropriate since it relates to student engagement solutions which had already shown proven results. The impact of these solutions was reviewed and the result is presented in Figure 7.17.

![Throughput Rate Results for QAS201T](image)

**Figure 7:17: Results of impact of intervention on QAS201T**

**ETT101T, MDR101B and MAT171T**

Interventions implemented on these subjects were limited to timetable restructuring and the introduction of myTUTor, as these are service subjects domiciled in Electrical Engineering, Mechanical Engineering and the Mathematics department, making implementation of the proposed solutions difficult. However, the two implemented interventions were monitored to observe their impact and the results are recorded in Figure 7.18.
A new network function was developed for the Industrial Engineering programme after the intervention, to observe the status of the identified bottleneck subjects and to detect new such subject(s) if any. The results are illustrated in Figure 7.19. The throughput rate (the primary metrics), dropout rate and exclusion rate (secondary metrics) for the department were then determined and the results are recorded in Figures 7.20, 7.21 and 7.22 respectively. The graduation rate for the Department of Industrial Engineering was also determined. The results are depicted in Figure 7.23.

Figure 7:18: Results of impact of intervention on MAT171T, MDR101B and ETT101T
Figure 7:19: Industrial Engineering network for 2007 to 2012

Figure 7:20: Throughput rate for Industrial Engineering 2007 to 2012
Figure 7.21: Exclusions for Industrial Engineering 2004 to 2012

Sharp increase is due to the merger of 3 different Technikons to form TUT
Figure 7:22: Dropout rate for Industrial Engineering 2004 to 2012

3 Sharp increase is due to the merger of 3 different Technikons to form TUT
7.3.2.2 Mechanical and Electrical Engineering departments

Interventions implemented in the subjects identified as having a low throughput rate in these two departments were limited because, as noted, the subjects were domiciled in different departments and access to monitor implementation was therefore limited. The interventions implemented were: restructuring of the timetable and introduction of myTUTor. The impact of these was monitored: results are presented in Figures 7.24 and 7.25 for Mechanical and Electrical Engineering subjects, respectively.

Figure 7:24: Results of impact of intervention on Mechanical Engineering subjects with a low throughput
A new network function was developed for Mechanical and Electrical engineering programmes after the intervention to observe the status of the identified bottleneck subjects and to identify the new bottleneck subject(s), if any. This was done and the results are depicted in Figures 7.26 and 7.27 for the Mechanical and Electrical Engineering departments, respectively.
Figure 7:26: Mechanical Engineering network function for 2012
In this chapter, the improve phase of DMAIC problem-solving methodology was applied to the National Diploma Engineering Higher Education System. New processes were developed and simulation was done to monitor process changes using system dynamics principles and methodology including: problem formulation, time horizon determination, dynamic hypothesis formulation, causal loop development, as well as development of initial and detailed models which included sensitivity analyses. The variables identified by the simulation were further varied until optimal points were reached. The optimal solutions obtained alongside other previously identified interventions were applied to the already identified bottleneck subjects in the analyse phase in the Industrial, Mechanical and Electrical Engineering departments to observe the impact on their throughput.

The next chapter considers the control phase of the DMAIC problem-solving methodology of LSS. This is important for the sake of continuity as regards the solution proffered and implemented.
Chapter 8: Control Phase

8.1 Introduction

The control phase is the final stage of DMAIC problem-solving methodology. This phase is dedicated to ensuring that process improvements are monitored, which should result in sustained improvement. The outcome of this phase is for new methods to become standardised in practice. Predicted financial returns must be constantly verified, particularly for the first three months of improvements, and lessons learned need to be documented and well communicated to ensure that in the future the same mistake or process is not encountered again. Tools such as work instruction, procedures, updated job descriptions and control charts are used to ensure that process improvements are sustained over time.

8.2 Standardisation of the new method

Process improvements realised in the improve phase must be standardised in order to continue realising the benefits of the improvement (Gupta, 2005). The old ways of doing things are replaced by the new ways. Process variation may have been reduced at this stage and it is therefore critical to maintain the new process parameters (Pande and Holpp, 2002). Some changes may require personnel to be moved or adjusted to meet the demand while, in other cases, process parameters may need to be altered to ensure minimal variation to the process. These changes cannot continue to take place if new standards are not put in place to guide personnel. Keller and Pyzdek (2005) list the following practices which are useful for standardising new process methods:

i. Process control is used to monitor process variation; controlling process input parameters results in minimum process variation.

ii. Control plans are used to define the method of control and to ensure that all potential causes of variation are addressed.

iii. Work instructions, procedures, process flows and flow charts are used to document process procedures and responsibility.

iv. Training of process personnel, to understand their new responsibility, is essential.
8.3 Measure bottom-line impact

A fundamental aspect of the control phase is to continuously measure the effect of the process improvements (Taghizadegan, 2006). This is a critical part of DMAIC methodology which sets LSS apart from other continuous improvement methodologies (Kalemkarian, 2006). Control plans should contain the provision for monitoring the process outputs, either as a method of control or as a sampling audit (Gygi and Williams, 2012). The process owner is responsible for continuously monitoring the performance metrics after improvement. The recommended time frame for a black belt to monitor process improvement and financial gain is three months. Thereafter random audits must be done from time to time to ensure that the process is still functioning effectively (Morgan and Brenig-Jones, 2012). A black belt can then close the project and hand over to the process owner who will monitor the metric daily.

In engineering education, as mentioned earlier, the processes take longer than in traditional manufacturing and other service industries. Therefore, in order to see significant change, the project must be monitored for at least a year to allow for two cycles of semesters. As crucial as process performance is, the on-going tracking of financial benefits resulting from the improved process or reduced process variation must be ensured (Morgan and Brenig-Jones, 2012). This is done monthly as part of the financial report and must indicate all expenses incurred as a result of process improvement from the define stage to the control stage. Project savings must be calculated and be reported on a monthly basis. It is recommended that there is a financially competent person in the team who will assist with monitoring the savings (Linderman et al., 2006). Both hard and soft savings for the project must be monitored and reported on.

8.4 Documentation of lessons learned

LSS projects must be accompanied by a project report. This document includes all activities that took place in each phase of the project: all data collected, tools used to analyse the problem and solutions for the problems (Morgan and Brenig-Jones, 2012, Keller and Pyzdek, 2005). This report ensures that if a similar project is attempted in future, there is a document which can guide the team as to what happened previously and how this problem was solved. In a more detailed format, Keller and Pyzdek (2005) and Keller (2011) proposed that the following key aspects must feature in the said report:

i. Project charter
ii. Summary of DMAIC phases
iii. Raw data (in an appendix) which were used to undertake the analysis
iv. List of expenses incurred during the project
v. Cost saving received from data and projected future cost savings
vi. Current status of the process and control plans
vii. Recommendation of future projects related to the projects
viii. Recommendation of future project leader and sponsors as a result of lessons learned from current project.

A project report must then be submitted to the project sponsor for signing off after it has been verified by a financial officer that the projected savings are accurate (Taghizadegan, 2006). The sponsor will circulate the project plan to all top management and master black belts for record keeping.

8.5 Application of control phase to the engineering higher education throughput problem

In engineering education processes, standardising the improved process was discovered to be the most effective way to implement the control phase of this project. It is essential to ensure that the correct thinking about the process is inspired in order to implement the control phase. The following elements constitute the activities required to implement the control phase or sustain the breakthrough improvements as suggested by Yang et al. (2011): thinking right, managing the process, valuing workers, leading improvements and counting the changes. Tools such as control charts, work instructions and visual aids are utilised during this stage in order to continuously monitor the process. Quality audits are employed to validate process improvements and compliance with customers’ needs, according to Gupta (2005).

In applying this control phase, a control plan to monitor process performance was developed, considering the process characteristics which need to be controlled, including the study guide, myTUTor, assessments, lecturer quality and students’ readiness using the following measuring techniques: process audit, online audit, assessment audit, check sheet and real time results. This was first applied to QAS201T and the process improvement was observed. Since the improvement resulting from this project was sustained and proved to be effective, this solution may now be applied comprehensively to other identified bottleneck subjects throughout the faculty so as to monitor the results.

8.5.1 Development of control plan

The control plan was developed for QAS201T to be able to monitor and control its process performance. Table 8.1 records the findings.
### Table 8.1: Control plan for QAS201T

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Specification</th>
<th>Measurement Techniques</th>
<th>Sample Size</th>
<th>Sample Frequency</th>
<th>Detection Method</th>
<th>Analytical Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Update study guide regularly</td>
<td>Twice a semester (December and June)</td>
<td>Study guide Audit</td>
<td>1 per subject</td>
<td>Twice a year</td>
<td>Observation</td>
<td>Stop the session and instruct professor to rectify</td>
</tr>
<tr>
<td>Update myTUTor</td>
<td>Twice a semester (December and June)</td>
<td>Online audit</td>
<td>Each subject</td>
<td>Twice a year</td>
<td>Observation</td>
<td>Stop the session and instruct professor to rectify</td>
</tr>
<tr>
<td>Conduct assessments (formative and summative) through myTUTor</td>
<td>At least six assessments per subject</td>
<td>Online audit</td>
<td>Two subjects</td>
<td>Once per months</td>
<td>Report from teaching, learning with Technology by department</td>
<td>Give feedback and request additional assessments for students</td>
</tr>
<tr>
<td>Group assessments</td>
<td>At least one per subject</td>
<td>Assessment audit</td>
<td>Each subject</td>
<td>Once after three months</td>
<td>Observation</td>
<td>Give feedback and request additional assessments for students</td>
</tr>
<tr>
<td>Lecturer’s readiness for teaching</td>
<td>At least one classroom visit per lecturer</td>
<td>Check sheet</td>
<td>One class per lecturer</td>
<td>Once a month</td>
<td>Observation</td>
<td>If not prepared, address the matter</td>
</tr>
<tr>
<td>Student’s readiness for class</td>
<td>Assess each session using clicker tool</td>
<td>Real time results from clicker report</td>
<td>All students in class</td>
<td>Each contact time session</td>
<td>Teaching, learning with Technology within departments i.e. lickers</td>
<td>If concepts not understood, repeat the session</td>
</tr>
</tbody>
</table>

#### 8.5.2 Training

Training was given to all Industrial Engineering lecturers on myTUTor, including how to upload assessments and how to monitor student engagement. Support in terms of administrative assistance to assist lecturers to upload their assessments on the Respondus software which uploads assessments to the Blackboard was given to all lecturers. Continuous audits are being performed to ensure that standards are maintained.
8.5.3 Monitoring of myTUTor utilisation

In order to monitor the utilisation of myTUTor, data was collected from myTUTor as to how many students access this system regularly. This revealed that a mere 30% of the students do so. This was regarded as a low figure as the researcher had anticipated 80% access, and a minor survey to determine why students are not accessing myTUTor as often as they should was conducted. The results revealed a space problem at the computer lab, while the lack of a wireless internet facility on the campus was affecting students’ access to the internet anywhere on the campus. The project to implement a wireless connection and to increase the number of computer laboratories was implemented so that the majority of the students are now able to access the internet at anytime and anywhere in the university.

8.5.4 Monitoring of process improvement of QAS201T

In order to ensure continuous improvement on the QAS201T throughput rate, its throughput was monitored from 2010 to date to determine if process parameters were being adhered to. For the first semester of 2010, the subject throughput rate moved from 38% to 71% and a significant improvement was recorded. QAS201T saw its best student achieving a distinction in this subject for the first time in 10 years. The proposed solution is effective as is evident from this performance over a period of three years, since students were passing the subject as predicted. The next step was to ensure that this improvement was sustainable, even when there is staff turnover in the subject under investigation. This was achieved by: updating lecturer workload on myTUTor regularly, monitoring student participation regularly in class and in their use of myTUTor for formative and summative assessments and because teaching with technological equipment became an integral part of the lecturing sessions.

8.5.5 Monitoring of financial gain

There is an annual potential gain of R477 090 from the TIG and operational costs for the Department of Industrial Engineering. If throughput increases from 14% of students who graduate after three years of study to at least 30%, there would be an additional R1,021,136 available annually from TOGs, as per the DHET guidelines. Although the faculty throughput has not yet reached the desired rate of 30%, if each department is able to increase its throughput by 5% for the next three years, by 2016 the faculty will be on target, because engineering education is a long process as has been indicated and improving it takes time.

8.5.6 Subject dashboard system

The subject dashboard system was developed to indicate when the throughput of a subject is becoming bottlenecked. Taken from the network function in Chapter 6, Section 6.2.4.2, this dashboard
will assist the department and faculty to identify when a subject is in a critical position and resources for intervention must be assigned as required.

8.6 Summary

It became evident that LSS tools can be used to improve processes, and that the same methodology may be applied in other departments as well, particularly Mechanical and Electrical Engineering, since Mechanics and Electro-Technology are shared subjects within these three departments. As discussed in the improve phase, if these departments do not increase their subject throughput, the chances of the faculty throughput increasing are minimal. This requires a collaborative effort among all departments within the faculty.

System dynamics focuses on endogenous factors, which mean that the changes which need to take place will be within the faculty domain; therefore it will be relatively straightforward to effect the required changes. The control measures implemented within the faculty are easy to monitor and the control plan clearly indicate all areas of control within the system.

The next chapter, Chapter 9, discuss results from Define to Control Phase, this chapter explains how LSS tools were implemented to solve engineering education throughput problem.
Chapter 9: Discussion of Results

9.1 Introduction

This chapter discusses all the results from the define to the control phase of LSS problem-solving methodology, including the implications of its application to improve throughput rate of the engineering higher education process.

9.2 Define phase

The results of the business case in the define phase indicated that improving student throughput is important for the given faculty, because the DHET subsidises the university based on the number of students enrolled for the subjects and those completing the programme. Table 5.2 indicates that the university loses potential revenue of about R30,418.49 per student each time a student repeats the subject. In addition, the student is preventing other students from obtaining a place at the university due to scarce resources. Moreover, the industry needs engineers, technologists and technicians. It is therefore important for the department to solve the throughput problem for the sake of its own viability as well as alignment with national objectives for Higher Education in South Africa. These state that the long-term goal of increasing the overall participation rate of producing graduates must be complemented by strategies to increase graduate outputs in the short to medium-term, in order to ensure that the current demand for high-level managerial and professional skills is satisfied.

An analysis of the historical data reveals that the Department of Industrial Engineering throughput rate for the National Diploma programme at TUT was 14% for 2010 as shown in Figure 4.1, corroborated by the report compiled by Scott et al. (2007) indicating the national throughput rate for engineering National Diploma programmes at UoTs in South Africa stood (at that time) at 17%. The department’s throughput rate is below the national level and this is problematic as discussed previously. The throughput rate for the Department of Industrial Engineering is the lowest in the given faculty. This indicated that the focus should be on improving this department’s throughput rate and to identify where scarce resources should be focused to obtain optimal throughput improvements by using an applicable unified systematic approach. This will result in an increased throughput rate of at least 16% for the department by 2017. Results shown in Figure 4.1 indicated that Industrial Engineering reports the lowest number of students who graduated from 2004 to 2009, the graduation rate being 26%, with Electrical Engineering being the best performing department in terms of the
number of students who graduated. However, on examination, the retention rate data reveals that Industrial Engineering has a 20% retention rate and Electrical Engineering a 36% retention rate (Figure 1.1). From this data and the fact that Industrial Engineering is a small department where, if changes to the system need to happen they can be implemented easily, it was decided to start with the Industrial Engineering department and then roll it out to other departments after solutions had been validated.

A Pareto analysis compiled from the 2004 to 2010 data (Figure 4.2) indicates that the main variables affecting student throughput in the Industrial Engineering department, which has been prioritised from variables listed in the data collection section are:

- Priority 1: \( x_1 \) Student subject failure
- Priority 2: \( x_2 \) Student dropout
- Priority 3: \( x_3 \) Student not getting or waiting for WIL I or WIL II and
- Priority 4: \( x_4 \) Student failing WIL I or WIL II.

Variables which from the Pareto analysis were found to have made a major contribution to student failure are \( x_1 \) (students subject failure) and \( x_2 \) (students drop out) as shown in Figure 4.2. Variables \( x_3 \) to \( x_n \) do not make a significant contribution to student failure; however, they were included in the analysis for further investigation.

Figure 4.3 indicates the high-level process flow of an engineering education process map which assists in understanding the process better. As the process was evaluated, many aspects which were not previously known are revealed and potential improvement opportunities were identified. The process flow indicates an overview of the entire process. The project starts when students apply to study at TUT and lasts until they graduate. The swim line process map in Figure 4.3 gives the overview of the process which results in customers' needs to be met and in this context means that students progress from one level to the next. It also helps to identify possible areas of required interventions, highlighted in red (Figure 4.3), which the faculty and the department are able to control.

SIPOC analysis was used to identify potential \( x_s \) which might have an impact on \( Y \). It helped to understand the process better and to ensure that all possible variables are accounted for during the analyse phase. Figure 4.4 outlines the SIPOC analysis for the engineering education process.

### 9.3 Measure phase

Figure 5.1 indicates areas where non-value adding steps are to be found in the process. These are possible waste areas in the system: reworks associated with student assessment results not being
favourable; student repeating subject; student dropping out and student appealing for remarking. These non-value adding steps must be minimised or eliminated from the system in order to improve process efficiency. Value enabling process steps identified in this process are: registration, enrol for subject, receive feedback from, assessments, year marks feedback, receive feedback from exam and graduation. The value adding processes are: attending lecture session; student studying or interacting with subject matter; writing assessments and writing exams.

The detailed process map has validated areas to be focused on when analysing the problem. Student repeating subjects was identified as a non-value adding process from the Pareto analysis and results were further validated by the process flow map. Data would be collected on those non-value adding processes in order to determine how severe the problem is. The engineering education process requires two processes working concurrently to achieve the desired results, which are: students’ learning process and lecturers’ teaching process. The non-value added steps from the lecturers’ point of view were identified from Figure 5.2 which shows the “as is” process for the lecturers. The value adding processes from the lecturers’ point of view are: lecturer prepares for class and lecturer delivers a lecture, while value enabling processes are: facilitate assessment; grade assessments; provide feedback; mark exam and exam statistics and submit results. The non-value adding processes are: attend to student’s appeal; reassessing students and conduct and mark re-exams.

The results drawn from the MSA analysis, as shown in Figure 5.3, revealed a minimal contribution by the RR Part, suggesting that the operators collected data in a uniform manner. The results also revealed that collected data had similar readings as the Measure by Operator graph, which is almost straight. This validates the view that the operators performed uniformly in terms of reading the data. The RR Part* Operator Interaction graph shows whether any given data sheet was difficult to read by any particular operator. Figure 5.3 revealed that Document 5 was difficult to read, since most data collectors recorded errors with regard to that document. There were 10 distinct categories which were reported on, thus the measurement system was deemed adequate for the variable data. The results of this study indicated that the operators were in good standing concerning the data collection; therefore they were able to continue collecting data from the MIS and have the survey administered to students.

Cost of poor quality was calculated as presented in Table 5.2, using the following categories: internal failure costs, external failure costs, prevention and appraisal costs. The data used were obtained from TUT’s MIS section. The DHET determines the money to be paid to the university based on its enrolment
plan and actual number of students enrolled for the last two years. The total grant which the university receives from the DHET is determined by TIG, TOG, ROG and IFGs with allocations of 56%, 14%, 12% and 6% respectively. The portion of the money the university loses is associated with the TIU which is calculated by multiplying the weight of the programme given by the DHET guidelines with FTE, which is a full load or full credit a student is expected to obtain at the end of the year. A single FTE is equal to 2.5 TIU and the DHET will pay the FoEBE R10,029.00 for 2011 and R10,499.00 for 2012 per single FTE. Thus, if a student does not take a full load, which is equal to a single FTE, the department loses funding. The majority of the students at least fail one subject per semester, which normally has a weight of 0.083 each. The total number of students registered for 2011 and 2012 was 380. Assuming that at least half of them failed one subject per semester, the Industrial Engineering department lost R4,623,610.48 for the year 2011 and R4,575,890.69 for 2012 from TIG. Details of the cost of poor quality are recorded in Table 5.2 for the Industrial Engineering department for the year 2011 and 2012.

For the TOG, the faculty graduation rate was at 14% for 2011 and the Industrial Engineering department undergraduate graduation rate was 9.7% which translates into 37 students graduated and 27 students graduated for 2012 translating into a graduation rate of 5.7%. For 2011, if the graduation rate had been 14% then 54 students would have graduated and similarly for 2012 with an assumption of 14% graduation, 66 students would have graduated. The financial implications of this are provided in Table 5.2.

The throughput rate was used as the baseline metric and the graduation rate used as the secondary metric. The difference between these two measurements is that the graduation rate metric doesn’t take into consideration how many years the students stay in the system. It is therefore distorted because the students might take six years to graduate, but they will be counted as though they graduated within three years. Throughput rate was chosen to be used as primary metric even though the university does not generally pay so much attention to this because the number of enrolments and graduation rate is used as the basis for funding by the DHET. Other secondary metrics are the number of students who drop out and number of excluded students. As throughput increases, student dropouts and exclusions are supposed to decline therefore monitoring this metric as secondary metric was found suitable. The identified matrix which is intended to be improved in this study is directly related to quality, cost and delivery, with the aim of making the process better, faster and on time.

It was discovered that, as a production process, an engineering process does not have actual tangible defects since it is a service process. However, the defects were defined as students failing a subject,
thus a DPMO was able to be calculated and used to monitor quality. The following items represent
the nomenclature and relationships which were applied, with modifications, to fit the application to
the engineering education process:
Defects (D) – Student who fails any subject
Units (U) – the number of students who enrolled for the Industrial Engineering programme
Opportunity (O) – the number of subjects to be done in the department.
The result on critical to quality metrics shows that DPMO value of 428 024 was then established from
data of the cohort entering 2004 to 2010.

The critical to the cost metric was the cost associated with a student repeating a subject. The cost of
failing a subject per student, as presented in Table 5.2, amounted to R4,623,610.48 for the year 2011.
This amount is significant and it can be reduced drastically, if not completely, by increasing the quality
(the throughput) in the process. It was decided not to use this metric to measure process performance
because if the quality improves, these savings will be realised. The focus was placed on improving
throughput within each subject, which will in turn increase the graduation rate, resulting in the
department being profitable.

It is of the outmost importance that students complete their studies within the three year period
assigned to them in order to prevent costs associated with repeating subjects. Currently the average
number of years to complete the Industrial Engineering diploma is five years and five months. In
addition, according to Scott et al. (2007), the national statistics indicate that the majority of the
students complete their studies after five years. In this research it is critical to deliver because, if
students stay in the programme longer, they take the space of other students who could have been
studying and they also lower throughput rate. Improving the number of students passing the subjects
will result in improving the cost and decreasing the number of years spent in the system.

Using data from the MIS, Figure 5.4 illustrates the throughput rate of the Department of Industrial
Engineering which was used as process baseline. The historical data used was taken from students
entering the department from 2004 to 2010 and who graduated in three years (in record time). The
average throughput rate of the Department of Industrial Engineering from 2004 to 2009 is 14%, which
is lower than the expectation of the DHET and the national graduation rate; hence the national
strategic plan objective is not being met.
A DPMO value of 428 024, established from data of the cohort entering 2004 to 2010, was then used to calculate the DPU which is DPMO x 10^-6. Data collected from the MIS shows that the number of defects in the process from 2004 to 2010 is 1 005 and the total number of students (units) is 2 348 which provides the number of DPU of 0.43. The probability of obtaining zero defects (yield) was calculated to be 0.6505. This means there is a probability that 65% of the students will graduate in three years. Therefore, the value of DPU obtained was used to estimate the Z variable equivalent from the normal distribution table, and a 1.5 shift was factored in from which the sigma level value of 1.68 was obtained. The sigma level of 1.68 means that the process is not capable according to Table 5.1 because for any process to be capable the sigma level should be ≥3.

9.4 Analyse phase

The response rate of the questionnaire was 77.09% which is adequate to obtain reliable information. The result of the data analysis as presented in Tables 6.2 to 6.8 shows that the group of respondents consisted of 69% male and 31% female students. Of the respondents 78% fell in the age range of 18 to 22 years, with the majority stemming from Limpopo and Gauteng. It is important to understand from which province the majority of the students come, as this gives an indication that the majority of the students are moving from Limpopo to Gauteng. This is understandable as there is no UoT offering an engineering programme in Limpopo. For this reason accommodation during studying may well be a vital issue as indeed the issue of poverty since Limpopo is one of the poorest provinces. Thus the student joining TUT from Limpopo might well experience financial challenges. Table 6.2 also indicated that 29% of the parents/guardians were not employed, while 46% of those employed earn less than R50,000 per annum which is a significant value that may impact on the financial viability of the students, ultimately affecting their performance and dropout rate. It was also revealed that 4% of the students have been in the system for over six years, during which they have been contributing to losses and depriving other students of the opportunity to enter the system.

The analyses relating to students failing engineering subjects as shown in Table 6.3, indicate that 44.02% of the students failed at least one subject in a semester, followed by 38.76% who failed two subjects in any one of the semesters which means the majority of the failures were recorded in the first year of their studies. It was clear from this study that first year subject failure is still a huge problem. It is therefore important to emphasise first year subjects to support the students. The study also revealed that none of the students actually failed WIL. The reason for this is that students only register for this subject after they have found a placement in industry. This means that if any student is unable to find a placement, they drop out in Semester 4. A significant number making up 4.5% of...
the students, fall into this category. Something needs to be done to assist the students with regard to their placements.

The Chronbach’s alpha test performed to check internal consistency on factors affecting students’ performance gave a value of 0.7785. The logistic regression test, subsequently conducted in order to determine the factors relating to student achievement, gave the result of a P-value shown in Table 6.4 using the P-value of 0.05 as the cut-off point. This indicated that the factors outlined in Table 6.4 have a significant relationship with student achievement.

Whilst using factor analysis to form data reduction, three latent constructs emerged as presented in Table 6.5. Items that correlate with each other have been pooled together and in this way a factor was identified. It was concluded that the majority of factors that contribute to student performance fall under matters relating to the academic schedule, adaptation to the learning environment and aspects of teaching and learning. The results also indicated that student performance is strongly linked to student engagement with staff members of the faculty and peers. The majority of the factors identified contribute to various aspects of the learning environment and student engagement while studying. These results are partly confirmed by Baars (2009b) who said student performance is related to the learning environment and student engagement while studying.

Table 6.6 reveals that approximately 60% of the sampled students dropped out of a certain programme after their first year of study and Table 6.5 indicated that possible reasons for this could be as a result of students not adapting to the learning environment, students not being well prepared for a higher education programme or as a result of peer pressure or distraction. It could on the other hand be as a result of a lecturer not using the right methodology approach, the academic schedule being too hectic, lack of proper orientation and mentoring and lack of time for the student to engage with academic staff. Students being admitted for programmes they are not capable of doing can be another source of this problem. Baars (2009b), Charlotte and Lori (2004) and Nariman (2007) agreed that factors affecting student dropout are complex and sometimes psychological in nature and that they vary from one environment to another. Students were therefore asked to rate the factors that they believed might cause them to drop out. From the dropout analysis none of the factors showed a P-value of less than 0.05 (Table 6.8) after logistic regression analysis. It was then concluded that these factors are not the direct cause of students dropping out, but might be combination of different factors which is a problem of linearity. Since the key element which leads to student dropout is subject
failure, it was agreed that the department will focus on decreasing this failure rate which should decrease the dropout rate and increase the graduation rate.

Respondents were also asked to indicate whether they sought help after they failed the subjects or before they dropped out. Only 12 respondents answered this question, meaning that not enough data was available to make meaningful predictions or conclusions. Meanwhile 67% of these respondents said they had not sought help and 33% did ask for help. Approximately 66% of the respondents indicated that they had requested tutorial support and mentoring before they dropped out of the programme while 10% indicated that they had requested psychological help as well as assistance from the Head of Department. From this result it was also clear that respondents did not know that TUT maintains a department dedicated to support students in areas of learning styles, mentoring and psychological help. It was therefore important to engage in an awareness campaign regarding these services which are offered.

A bottleneck in any process results in a low throughput rate. In the FoEBE a subject with a minimum throughput rate of less than 50% was considered a bottleneck subject. The network map developed (Figure 6.1), illustrates the Industrial Engineering National Diploma programme structure and how the subjects are linked to each other through prerequisite subjects. This network was designed to allow the maximum flow of students from one area to the next. By observing the Industrial Engineering programme network, it is evident that it was designed to allow students to move from one subject to the other easily, thus maximising the flow of students from one level to the next provided they pass the subjects they were registered for. Nevertheless, bottlenecks occur for example, a delay caused by failing one subject means that the student will not be able to enrol for the next level subject unless he or she passes it. If the subject has a prerequisite, a student needs to wait for approximately six months while repeating the failed subject before registering for the next one.

Figure 6.2 in conjunction with equation 6.1 were used to calculate RTY for the engineering higher education process based on the data of the class that entered TUT in 2007 and finished in 2009. The RTY for the whole programme was then established to be 6.2% which is too low for the system. This is an indication that improving RTY for the system is critical. The result of the sub-division of the network structure (Figure 6.3) was used to identify the critical paths in the system and the bottleneck subjects were identified per sub-process as presented in Table 6.9. The implication of the five identified critical paths is that they are responsible for the overall low throughput, therefore attention and resources must be focused on these paths in order to increase the overall throughput rate.
From Figure 6.3, all the subjects with a RTY less than or equal to 50% in 2007 were identified and averages of their RTY between 2007 and 2010 were compiled as presented in Table 6.9 to determine the most critical subjects within this period. The subjects PHY101T and QAS201T were identified. These two subjects, which have a throughput rate of less than 50%, were responsible for the overall rate dropping. Meanwhile, if the RTY of PHY101T is improved, it will not have as much effect on the overall RTY as QAS201T because it has no prerequisite subject. That is why QAS201T was given more attention, especially because it is an S3 subject which, if a student should fail it, will block his/her way to graduation after putting in so much from both the student and the system.

Further analysis on the identified subjects with a low rolled throughput rate identified the following bottleneck subjects in the Industrial Engineering programmes, which have a throughput rate of less than 50%: PHY101T; MRD101T; MAT241T and QAS201T. In order to validate these results, the throughput rate of the mentioned subjects for the period 2007 to 2010 was compiled and the result presented in Table 6.10. Of these subjects, PHY101T and MRD101T are S1 subjects, and MAT241T and QAS201T are S2 and S3 subjects respectively. In order to improve the overall throughput rate, the focus should be placed on the subjects outlined in Table 6.10. To increase the throughput of the programme, the focus should fall on improving the RTY of QAS201T until it is equal to the other subjects with a low throughput. Increasing this throughput should result in an increase in the throughput of the programme. The average calculations of the throughput from 2007 to 2010 identified an average throughput rate of 51% for the subjects listed in Table 6.10. However, the rate is too close to the previous rate to be considered as a cut-off point.

Lean tools like 7 waste and 5S were applied to the Engineering Higher Education System to remove waste in the system. The 7 waste tool was used to bring the process to stability, starting with overproduction, meaning producing more than you need for a class from a lecturer’s perspective or what you don’t need from student’s perspective. Either way, time and resources will be wasted and this might result in students failing the subject. Over-processing waste is evident particularly from a lecturer’s perspective. Sometimes lecturers spoon-feed students to such an extent that students don’t know how to collect and make sense of information by themselves. Waiting is one of the wastes which was experienced. This was a result of some lecturer going over his/her allocated time in a session with students resulting in students waiting for venues for classes and laboratories. Motion waste was evident, although this was due to the design of classrooms and the space problems encountered by the faculty. Students have to move from one classroom to the next and this wasted about 75 minutes
a day. This is a lot of time since students could use this time for group work and other activities. Transport waste is associated with travelling from one area to the other. It was also identified that most of the students spend three hours on average commuting from their residential areas to the university. This can cause a strain on the students resulting in them sleeping during the session and missing the core concepts discussed in class.

Correction waste is related to time spent correcting errors, either marking or wrong information conveyed or repeating the subject which a student should have passed already. This waste is associated with scrap and rework in a manufacturing setup. Inventory waste is the waste related to students repeating the subjects. These students fill up the classrooms and new students trying to enrol for the subjects sometimes don’t get a seat. If this waste in the process is minimised or eliminated, quality of teaching and learning will improve thus improving the throughput of the department. Providing awareness training of these issues to lecturers and students and ensuring compliance will eliminate this waste in the process. Data as to how much waste was eliminated in this process was not collected since it was impossible to collect this from all students in the system. However the awareness resulted in both lecturers’ and students’ sense of urgency increasing and as well as their sense of the value for time.

Why students were failing QAS201T was investigated in order to determine the root cause of this phenomenon. A focus group of QAS201T students was formed to analyse why the students fail the subject. An additional focus group of lecturers from the Industrial Engineering department was formed to work together to determine why students were failing QAS201T. In order to ascertain the root cause of the failure rate of QAS201T, the cause and effect analysis tools were used. The cause and effect diagram seeks to identify potential $X$ which impact the $Y$. According to Arthur (2006) and Fairbanks (2007), in order to develop a cause and effect analysis effectively, a five why analysis must be performed. The question ‘why’ things are happening the way they are happening must be asked five times in order to determine the root cause of the problem. Using the diagram from the cause and effect diagram in Figure 6.4, five causes of students failing the subjects and alternatively dropping out of the programme were identified. Since this method is not a scientific method and is just brainstorming, the potential causes identified were related to the outcome of the survey.

Figure 6.5a and b indicate the results of the normality test of the data. The test indicated that for Test 1, data is not normal, however, for Test 2 the data is normal and it was therefore used for the analysis. Figure 6.6 (a) and (b) show results of the two sample T-tests conducted, which indicated that there is a significant difference in the mean of the two sub-groups. Table 6.11 shows that the $p$-value results
for this analysis is $p = 0.000$ which is less than 0.05. The null hypothesis is therefore rejected, which implies that the test results of students who study are not equal to the test results of the students who did not study. The results validate that students need time to study in order for them to pass tests or exams. It is therefore important for us to ensure that students engage with their work.

To understand the current situation the amount of time students spend per week studying QAS201T when they write a semester test or during a semester test week and after the semester test week, was investigated. In this regard, hypothesis testing was performed utilising two sample T-tests.

Figure 6.7 (a) and (b) present the result of the hypothesis testing which shows a significant difference between the two sub-group means. The P-value is 0.002 (Table 6.12), which is less than 0.05, therefore the null hypothesis was rejected and the alternative hypothesis accepted. The results indicate that the average time students spend on QAS201T during normal classes is less than the average time they spend studying this subject during a test week. These results indicate that on average students spend 38 minutes studying QAS201T per week as opposed to 91 minutes during a test week. The results also indicate that most students study during the semester test week. During normal classes, very few students study their work, hence the feeling of not having sufficient time to prepare for the test. This validates the fact that the students’ engagement with their work is important for them to pass the subjects. It also indicates that if the throughput of QAS201T is to be improved, there must be an increase in the amount of time that students spend studying the subject per week during normal lecturing time. The results of this test prove that if a student struggles to study and lecturers use traditional methods of teaching and learning, students will fail the subject. Occasionally, this might even lead to students dropping out.

The application of the network function and RTY calculation to the Mechanical Engineering department, being one of the related departments to the Industrial Engineering department, indicates a slightly more convoluted flow than that for Industrial Engineering. This type of flow causes bottlenecks, since if a student fails a subject, he/she cannot proceed to the next level subject if the subject is a prerequisite for the next level subject. There are three main flows in Mechanical Engineering, the Mechanics flow, Mathematics combined with Strength of Material and the Design flow. This means that if a student is experiencing difficulties in either of these steams, they will not be able to proceed and they either change their course or drop out. Figure 6.8 presents the network of Mechanical Engineering with throughput analysis. Subjects with a throughput of less than 50% were considered bottleneck subjects. In the Mechanical Engineering programme, there are eight subjects
which have an average rolled throughput rate of ≤ 50% and below with their sigma levels (Table 6.13). This analysis indicates that Mechanical Engineering subjects which are bottleneck subjects are spread over all semesters with the Mechanics sub-structure being the main problem area. This flow is critical since all subjects have a throughput in the region of 44%. It is also clear that ETT101T, which is a bottleneck subject for Industrial Engineering, is a bottleneck subject for the Mechanical Engineering programme as well, which explains the need for urgent intervention in this subject.

The network function and RTY calculation was also applied to the Electrical Engineering programme with a structure that has a more straightforward flow than either the Mechanical or Industrial Engineering programmes. The network indicates five critical paths namely: electrical engineering, mathematics, electronics, digital systems and a project. Similar to Mechanical and Industrial Engineering, if students cannot go through some subjects in these flows, they have to change the programme, drop out or be excluded. One element which Electrical Engineering has which Mechanical and Industrial Engineering don’t have, is project work as a separate subject, spread over three semesters. Electrical Engineering also has many specialisations, from light current to clinical engineering which provides different options for students to choose from. Figure 6.9 outlines the Electrical Engineering programme structures. The network shows a smooth flow from one semester to the next. The programme is well streamlined and although the structure was developed for all possible programmes in electrical, students can choose the critical flow they need to follow for them to specialise in a certain field. Figure 6.10 indicates that the worst bottleneck subjects are Software Design II (SFD 201T) and Electronics III (ELC331T) which is a concern because these subjects have a 39% and 36% throughput respectively. Other subjects which are below the 50% cut-off point are indicated in the Table 6.14. The analyses indicate that Mathematics I is the common subject with a throughput of less than 50% for Mechanical, Industrial and Electrical Engineering. The analysis indicated that for Electrical Engineering to improve throughput, the focus must be placed on Software Design II and Electronics III, thereafter the focus must be placed on other subjects with a throughput rate of less than 50%.

The analysis of the three programmes indicated that there are subjects which are common problem areas across the departments as shown in Table 6.15. These subjects require joint interventions in order to improve their throughput across all three departments.
9.5 Improve phase

The analysis phase indicated that subject failure is one of the key variables which impact negatively on faculty throughput. The use of RTY and network function identified subjects to focus on in order to create a significant improvement in the overall throughput rate.

The throughput rate for the TUT FoEBE has for the last five years been stable at an average of 14%. This model identifies key variables or policies which have a major impact on throughput and have actions and controls that can be placed on those variables which will result in a throughput increase. The engineering education process is a long term process, Therefore, for the model to show a true variation it must be modelled over a long period. In engineering education, process curricular changes generally take place after a decade indicating that a longer modelling process will enable us to see the impact of policy changes over that time period. Another aspect is the fact that it takes about six years for one cohort of students to go through the process, therefore, a longer time horizon is suitable for this simulation. As a result, a time horizon of 40 years was used from 2010 to 2050 which will give a clear picture of the impact of policies over a long period of time, as suggested by Frances et al. (1994).

Over the time period, throughput will decrease as a result of enrolment numbers increasing, students not being funded and students not being engaged in their studies. These will ultimately lead to a poor throughput rate. Throughput is referred to as graduating students after three years of study. It is important to again note that the model was built to represent a three year programme and not a six year programme. Figure 7.1 shows the effect of pass rate, dropout rate, funding and students in the system on graduation. This hypothesis assumes that there is a causal relationship between all these variables and the graduation which is referred to as throughput in this study. Through analysis, the casual loop was developed to describe key variables impacting on throughput as outlined by John (2000). There are three causal relationships in this diagram; the first is between passing/promotion, graduation, students in the system and current student quality. The loop outlines that passing results in graduation, which in turn reduces the number of students in the system and this impacts on current student quality. The second loop is between passing/promotion, graduation, carrying capacity, number admitted, student in the system and current student quality. Passing here also leads to graduation which in turn increases carrying capacity, which will determine the number of students to be admitted which in turn determines current student quality. The last loop outlines the relationship between passing/promotion, graduation, carrying capacity, desired enrolment, number admitted, student in the system and current student quality.
In the developed initial model, the main stocks and flows for this model are the aging chain representing the flow of students from first year to graduation as applied by Oyo (2008a) and Richmond (2004). This relationship is illustrated in Figure 7.2. Factors or policies affecting university throughput have been demonstrated by sub-models with feedback loops. The central part of the model outlines how students flow from one semester to the next and how factors such as dropout and success rate impact on this flow. The rates used for dropout differ from semester to semester as per the average data from the university system. For the sake of simplicity a semester model was shown, indicating how students enter the university, go through classes, at the end of the semester being promoted to the next semester or not, and how dropout occurs during the year and at the end of the year.

The concept of pass rate is a complex phenomenon due to variations affecting the engineering process. It is almost impossible to predict student performance, let alone average student performance as postulated by Schwartz and Washington (2002). The main dynamic factors contributing to student throughput and used to develop the initial model are pass rate values which were taken from the faculty data and have averages of 30%, 60%, 60%, 70%, 70%, 16.99% from Semester 1 to Semester 6 respectively. Dropout was represented by the dropout rate which the data gathers from the cohort analysis. According to our analysis, which also confirmed the statement by Watson et al. (2004), it is an established fact that the majority of the students drop out in the first year of entering university. With that knowledge in mind and data from the cohort analysis, the following dropout rates were used for the initial model; 0.33, 0.21, 0.22, 0.12, 0.07 and 0.1 from Semester 1 to Semester 6 respectively.

Figure 7.3 indicates the number of students graduating three years after entering the university. It is clear that the number of students graduating was increasing from 2010, until it reached a maximum in 2016 when 482 students are graduating each year. The model shows a graduation of 482 students per semester when the number of students in the system is at 10 500 as shown Figure 7.4. The results indicate that the initial model is suitable for the purpose of this study, since the main characteristics are represented in this model. In engineering education currently, about 1 500 students graduate per year after spending five years in the system and there are about 10 500 students in the faculty. Therefore the results of this initial model are close enough to be used for this prediction.

Figure 7.5 shows the results of sensitivity analysis with an enrolment of 3 000, 6 000, and 9 000 utilising the model baseline and a sensitivity analysis, to test the model when there is an increase in the
number of students in the system. These results reveal that if more students are admitted into the system, graduation increases from year 2010 to 2016. After 2017 the number of graduate remains constant. In fact, the graph shows that when student numbers increase, the number of graduate increases. The numbers increase from 125 in 2010 to 215 in 2016 if the number of students increases from 3000 to 9000, this is a significant increase although this in a real world is not sustainable since the system become congested by students not graduating and the numbers get to 11 000 after 5 years which is problem since faculty don’t have the capacity to handle more than 11 000 undergraduate students

The results of the initial model clearly demonstrate that increasing student numbers is not a long term solution to increasing throughput. Over time the throughput will be constant and if student numbers are continuously increased, the throughput will decrease as a result of a bottleneck in the system; this was also validated by Figure 7.6 which indicates how throughput reduces when student numbers increases. If student numbers increase and resources don’t increase, students will not get the assistance they need in order to understand the study material and to pass the courses they are enrolled in. This led to the need to devise a more detailed model to determine other variables in this system which might lead to an increase in throughput, as suggested by Oyo et al. (2008b), to answer the second part of the researcher’s dynamic hypothesis which seeks to identify casual relationships within key variables and test the impact of certain policies on the system, should they be adjusted.

Figure 7.7 shows the complete model for the engineering higher education process and Appendices H to M contain more details on this. Figures 7.8 and 7.9 respectively show the number of students who graduated and the number of students in the system without varying any factor. Considering all the factors that affect throughput in the detailed model, the graduation figure rose to 348 from 2010 to 2015. It then increased slightly to 376 graduates from 2015 to 2017, where after it remained constant at 376 until 2030 at which stage the number of students in the system is 10 500 as shown in Figure 7.8. This implies that the number of graduates decreases when all the factors are considered. It was 750 when these factors were not considered, but now stands at an average of 376 when all factors were considered. In order to know how these factors affect each other in the system with respect to their impact on the throughput rate, these factors were varied and their results were presented in figures, funding policy, academic exclusion policy versus impact of time spent studying, learning environment versus staff to student ratio, learning environment versus staff quality and a combination of all the factors. Details of the results are shown in Figures 7.10 to 7.16.
The result of a varying funding policy shows that it is an important aspect impacting on a student’s performance. At TUT the majority of students come from disadvantaged families and their parents therefore cannot afford to pay for their studies. This affects their performance since the institution has the policy that if student’s funds are not paid, they cannot progress to the next level, putting strain on their performance. This is in agreement with the findings of Oyo et al. (2008b).

To determine the effect of change in this policy, sensitivity analysis was done to illustrate the changes in the graduation figure, should the ratio of students who don’t need funding increase from 70% to 80% and 90% to show the impact of student funding on their performance. Figure 7.10 indicates the increase in graduation from 370 to 456 and 530 should the ratio of students who don’t need bursaries increase from 70% to 90%. This means that if TUT wishes to increase graduation rates, perhaps the management should look at enrolling students who will be able to fund their studies or consider the possibility of an increased bursary allocation for students needing a bursary. This result is validated by Braunstein et al. (2000), Wessel et al. (2006) and Wohlgemuth et al. (2007). Since different universities have different policies with regard to student funding, institutions need to understand their students’ environments and ensure that measures are put in place to assist good students who do not have the financial resources to pay for their studies.

Figure 7.11 shows the result of sensitivity analysis of varying the number of hours spent studying. In the analyse phase, time for studying or time students engaged in their work was outlined as a main variable affecting student performance. All other variables were kept constant and hours students are engaged a week were changed from 20 to 30 and ultimately to 40. When doing so the graduation rate increases as shown in Figure 7.11. The graph indicates that if students increase times spent studying, the throughput rate will increase from 299 to 387 and 436 for 20, 30 and 40 hours respectively in 2016. If we compare this with funding sensitivity analysis, it is clear than about 100 more students can graduate should funding be provided. By implication it means that even if we have brilliant students who have no funding, they will drop out and the throughput of the faculty will still be affected. This result is in line with the findings of Baars (2009b).

Figure 7.12 shows the outcome of the test carried out on the staff to student ratio as one of the important variables in this model. It is a known that if the staff to student ratio is too high, student engagement might be compromised which might lead to poor results. This variable was tested by keeping all other characteristics of the model constant and a sensitivity analysis test was performed on the number of staff to indicate if there will be an increase in graduation numbers should the staff
The results of the sensitivity analysis performed when academic staff numbers are at 60, 90 and 120 indicates that in 2016, throughput will increase to 375, 397 and 414 respectively, which means that increasing staff does increase throughput although not to the desired level. For every 30 staff members the faculty only gains about 22 more graduates. This is not enough considering that there is a need to improve its throughput by more than 50%.

Figure 7.13 indicates that the decrease in staff quality results in a decrease in throughput. In fact the number of graduates decreases by 100 graduates, should staff quality reduce from 100 to 80%. This is a huge margin. In a study to measure lecturer quality done by Basson et al. (2012), they outlined that one can measure a lecturer’s quality based on the way a lecturer interacts and engages with the student. From their study the following variables were taken as main criteria for measuring staff quality; years of experience in teaching; use of summative and formative assessments in class; and use of e-learning in the classroom. The result is interesting and testing this theory in our model was appealing. Figure 7.13 indicated that, should variables outlined by Basson et al. (2012) in their study be used to determine staff quality, the average staff quality for TUT is 80%. The results indicate that the graduation will reduce from 375 to 135 and the faculty will only be able to graduate 135 by year 2016 and is supposed to graduate 376 by 2016. This difference is huge. It is therefore imperative for the institution to ensure that staff quality is part of the university required standard without compromising the quality of education given to students.

Having been able to test these variables individually, it was clear that there can be some feedback loop activities if one simulates combinations of some variables. Figure 7.14 shows the sensitivity analysis result of the three combinations simulated. The combination with the increase of the proportion of students who do not require funding from 0.70 to 0.90 and increase of time students are engaged in their studies from 20 hrs to 40 hrs and a staff quality at 80% has the highest throughput rate of 136 to 240 by 2017. This means that if staff quality is at 80%, an increased proportion of students who don’t need funding, and at the same time increase student engagement from 20 hrs to 40 hrs a week, throughput will increase from 136 to 240 by 2030. This is a 56% increase in throughput. This is considered the optimal solution for the simulation because further variations and increases of the factors did not have a significant increase in the throughput. The model indicated that if these variables are improved, they can produce 56% increase on throughput by 2017. This will be very good for the faculty since the aim of this project was to improve throughput by at least 36% by 2030.
Although this model shows that the increase of throughput is possible should the mentioned variables be improved, the implementation strategy needs to be put in place. Simulations confirm the variable outlined during analyse phase, which was time spent studying. In addition to this variable, simulation also outlined two more variables namely student funding and learning environment and if these variables are changed together with time spent studying, the results will improve over time. These results confirm the facts stated by Ferrin and Muthler (2002) and Keller (2011) which outline that some variables are subtle and they interact with each other. Therefore, in order to understand their impact, the process output simulation must be used. It is now understood that in order for the faculty throughput to improve, all departments must collectively work on these significant factors and come up with solutions which can be implemented by all departments.

The Industrial Engineering department subject QAS201T was the first subject to receive attention in order to improve its average throughput rate of 43% from 2007 to 2010. The first suggested solution for students failing the subject was to increase the student’s engagement with the subject, in particular during the time when there is no test week. This was carried out by increasing the number of class tests and the amount of group work organised for the students. Increasing the number of class tests force the students to study before they come to class and assists them to ask questions when they do not understand the work. Group work, on the other hand, assists students to learn from each other. Studies indicate that students learn better from their peers. The second solution was to introduce e-learning (myTUTor) for this subject as suggested by Nora and Snyder (2008) and Hendrik and Serfontein (2004). All the learning materials were placed online for students to access when they wished to do so. This helped the students to have access to the work done in class, even when they did not attend classes. The introduction of e-assessments, in particular, was effective because it also forced them to test their understanding of the work covered.

After the implementation of the mentioned measures, the results in Figures 7.15 and 7.16 indicate that there is an improvement in the test results. The results of the student tests after the initiatives had been implemented, improved significantly. The test average before the improvement was 49%, and after improvement, the average was 67%. This indicates that if students engage with their study material effectively, the students who are prone to pass the subject, might improve their performance. Hence, strong students will generally do well, whether there are initiatives in place or not.
However, improving this subject throughput alone will not lead to a huge jump in the faculty throughput. For that to happen, the Departments of Industrial, Mechanical and Electrical Engineering must work together to improve student engagement in those subjects with a performance of 50% and less in their departments because some of these subjects are common as indicated in analyse phase. If this is done, the faculty throughput will increase. If the student engagement is increased from 20 hrs per week to 30 hrs per week, the model predicts a 29% increase in throughput by 2020. This is a huge increase, provided that other variables remain the same.

The second variable outlined by the simulation model as key variable is student funding. Student funding has been outlined by Doolen and Long (2007) as one of the levers which determines whether a student will stay or leave the university. Student funding, however, in the FoEBE is an external factor since the faculty has no influence over this. The funds come from the university structure and very little can be done to influence this variable.

The suggestion to improve this variation is twofold: either the faculty only admits students with bursaries or of which they have proof that their parents will be able to pay their fees, or the faculty needs to go to industry to solicit funds for student bursaries. The former will be a problem since enrolment numbers will be affected by that strategy. Therefore, the only way is for the faculty to look for third stream of income which can generate funding for the students. If student funding is increased by 90%, it will result in a 49% increase in throughput by 2015 and about an additional 6% by 2020. This data outlines that indeed student funding can yield significant results if improved. In order for this improvement to be implemented, resources need to be allocated from the Dean’s office and the university management as such. Implementation of this change is difficult if not impossible, although it will have significant potential, but it is not viable for the university to implement for now.

The last variable considered was the lecturer to student ratio in an improving learning environment. It was suggested that, as it is costly to hire more professors which are controlled by the university management structure and the DHET funding provided, it is much easier for current lecturers to use technological tools to aid learning as advised by Hendrik and Serfontein (2004). Technological tools will free their time in terms of contact hours, although students will still be able to engage with a lecturer in their own time using media aids.

This solution was found to be viable as the faculty as a whole was moving towards an e-learning strategy. Equipment and support was available, but it was not as yet utilised by the professors. It was
recommended that all professors should start using e-learning material such as PowerPoint presentations, myTUTor and Blackboard applications for formative and summative assessments and audio visuals. This will enable the students to engage with professors' work in their own time and any time when they wanted to. This solution was deemed to be appropriate since it related to the student engagement solution which already had proven results.

The impact of these interventions on QAS201T has been outlined in Figure 7.17. The analysis indicates that in 2007, the throughput rate of QAS20T was at 35% and in 2008 it decreased to 27%. During this time the intervention was not in place yet and in 2009 it rose to 38%. However, after the intervention was put in place in 2010, the throughput rose from 38% to 71%, from where it continued to grow to 77% in 2011 and to 91% in 2012. This indicates a 53% improvement in the throughput rate of this subject. This subject used to be a bottleneck subject, but three years after the intervention, it is one of the best subjects within the department and this is the result of changing the teaching and learning methods both inside and outside the classroom.

After noticing this huge improvement in OAS201T, and understanding that some subjects identified as bottleneck subjects need to be improved as well, the decision to implement some of these initiatives was taken. ETT101, MRD101T and MAT171T are service subjects, meaning they are offered by a lecturer from the Electrical and Mechanical Engineering department. This situation limits the nature of interventions which can be initiated in these subjects. Firstly, timetable changes were implemented with the aim of increasing student engagement in class and giving sufficient time for group work. The second intervention was the use of myTUTor for those subjects. The results of these interventions were indicated in Figure 7.19. The graphs show that there is an improvement particularly in ETT101T and MAT171T. For ETT101T there is a steady increase from 37% in 2008 to 79% in 2011 and a slight decline of 14% from 79% to 65% in 2012. For MAT171T there was a huge increase from 50% in 2007 to 81% in 2011, then declining to 67% in 2012. Although these initiatives were not strictly enforced and the teaching and the learning style initiative was not yet implemented, results were favourable. MRD101B results indicated an increase from 50% in 2007 to 71% in 2009 followed by a slight decline to 60% in 2011 and again increasing slightly to 65% by 2012. It is not clear as to what contributed to the decline since other subjects have increased their performance. Further investigation needs to be done to determine what caused this decline.

Figure 7.20 shows the Industrial Engineering throughput rate analysis for 2012. From this analysis it is clear that there was a huge reduction in the number of subjects which were considered bottleneck
subjects in Industrial Engineering. Initially there were four subjects of this type in 2010 but in 2013 only two remained and they are not the same as those identified in 2010. In order to continuously improve the throughput rate for the department, the focus will be placed on these two subjects for future studies.

The results of this intervention resulted in the overall throughput rate for this department increasing from 8% in 2007 to 31% in 2010, while in 2011 it increased to 33%, but in 2012 decreased slightly to 23%. This indicated that if these new initiatives are upheld and are implemented in all subjects, the throughput rate for the department might increase significantly by 2015 to a level above the national statistics indicated by Scott et al. (2007). Although there was a slight decrease during the year 2012 as a result of the new registration policy for WIL I and WIL II subjects, it is clear that the initiatives implemented produced favourable results. Therefore, if subjects with low throughput rates can be identified and resources channelled to them in order to improve their performance, the improvement of throughput can be achieved. Figure 7.21 also indicated that the number of students excluded decreased from 25 in 2009 to 10 in 2012. This indicates that indeed when a subject’s throughput increases, exclusion will decrease and one can expect increased programme throughput and larger numbers of students graduating. This was confirmed by the results indicated in Figure 7.22 which show that the overall dropout numbers have decreased. This result indicates that the total dropout number in 2009 was 30, but decreased to 15 in 2012. These secondary metrics are important to monitor because they indicate whether the solution implemented is resolving the problem or whether it is just shifting the problem to other areas. The results do indicate that there is a significant improvement proving that the solution is effective. LSS problem-solving methodology requires that the process remains stable before and after improvements have been made to ensure continuous improvements in the process. It was decided that the department would continue monitoring the throughput rate since significant improvements were seen on the subject level.

Figure 7.23 illustrates the results of the graduation rate of the Industrial Engineering programme. These rates were calculated by dividing the total number of qualifications awarded at an institution by the total number of students enrolled in the same year. This gives a rough measure of programme performance, but does not take into account fluctuating enrolments which have a significant impact on the graduation rate. There seems to be a decline in graduation from 2007 to date, but the number of registered students has increased from 263 to 340 for 2007 to 2013. Although the throughput is increasing, the graduations seem to be declining due to the large number of students enrolled. If the
numbers of registering students remain the same, the impact of the increased throughput on the graduation rate will be visible.

The analysis for the Mechanical and Electrical Engineering departments was undertaken to determine if there was an improvement in the throughput rate as a result of the few interventions implemented. Figures 7.24 and 7.25 illustrate the performance in the subjects which were identified as bottleneck subjects during the initial analysis. It indicates that for Mechanical Engineering subjects there is a steady increase. Although this increase is not significant because the teaching and learning style initiative was not yet implemented, it was observed that all subjects had moved from the bottleneck cut-off point of 50% from 2010 to date. Figure 7.25 also indicates that for Electrical Engineering subjects, there is a steady increase in throughput in almost all the subjects, though it is clear that some subjects are still below the 50% cut-off point. ELC331T, SFD201T, ESL111T, ELC211T and MAT171T have recorded an average improvement rate of 12% from 2010 to 2012 even though they are still below 50%. These improvements indicate that, even if major initiatives are not implemented within a department, giving lecturers and students flexibility to improve student interaction, may lead to improved throughput.

Figure 7.26 shows the network function for the Mechanical Engineering department. Only three subjects, namely SMP301T, TMH301T and ASA301T are bottleneck subjects, an improvement since 2009 when six subjects were identified as bottlenecks. This represents a 50% improvement. Figure 7.27 depicts the network analysis for Electrical Engineering, from which it is clear that some subjects which were identified as bottleneck subjects are now no longer bottlenecks: MAT357T, DSY231T and DSY341T have more than a 50% throughput. The analysis also indicates that there are new subjects which are now reporting a low throughput rate, particularly the subject PJT201T which indicates a 0% performance. This is due to the fact that there were no students registered for this subject in 2012. These results indicate that in order to improve throughput, it is important that all departments are implementing the same initiatives to ensure that the impact of the initiative is seen on a larger scale. Improved subject performance also indicates that if these initiatives are sustained, they are effective to improve throughput in any department. Hence, significant throughput rate improvement can be seen from the departmental level over time.

9.6 Control phase

In the improve phase, simulation was used to determine the impact of changing variables that affect throughput within the engineering education system. The following variables were varied using system dynamics modelling: entry student quality, student quality, staff quality, staff to student ratio,
financial exclusion, academic exclusion, voluntary exclusion, impact on time spent studying and learning environment. The results of the simulation indicated the following variables have the greatest impact on student performance when varied together, funding, impact of time spent studying and staff quality. The following solutions were implemented in three departments: change of timetable, introduction of e-learning (myTUTor) and new network function. The data collected after implementation indicated that there was a significant improvement since implementing these initiatives, particularly on a subject of the Industrial Engineering department, OAS201T, of which the throughput improved by 53%. In order to sustain these improvements, controls must be put in place. New processes and procedures must be developed, standard of new processes must be developed, improvements must be monitored to determine financial benefits if possible and solutions must be documented to ensure the availability of lessons learned.

In the engineering education process, standardising the improved process seemed to be the most effective way to implement the control phase of this project. As pointed out by Morgan and Brenig-Jones (2012), the said phase ensures that the solution to the problem is sustained in order to control gains and sustain improvements. In order to monitor process performance as outlined by Keller (2011), data was collected from myTUTor to ascertain how many students access myTUTor regularly. This data indicated that only 30% of the students accessed myTUTor regularly. The numbers were low since a 80% access rate was anticipated. The team therefore sent out a small survey to determine why students are not accessing myTUTor as often as they should. The results indicated that space problem at the computer laboratories and no wireless connectivity on the campus prevented students from accessing internet anywhere while they are at the university. Wireless internet connections were implemented and the number of computer laboratories was increased from one to three within the faculty. The majority of the students can now access internet at anytime and anywhere at the university.

The second solution related to time spent studying, which was ensuring that student engagement in class, is enhanced through the use of group and class activities, lecturer workload was assessed and lecturer responsibilities were outlined clearly on the workloads document. The regular use of myTUTor, monitoring student participation and the use of myTUTor for formative and summative assessments have become an integral part of the lecturing sessions and the workload document became part of the performance management system. Lecturers are also expected to put all requirements in the study guides. Training was given to all Industrial Engineering lecturers on uploading myTUTor, how to upload assessments and how to monitor student engagement. Support
in terms of administrative assistance to assist lecturers to upload their assessments on the Respondus software, which uploads assessments to Blackboards, was given to all lecturers. Continuous audits are being performed to ensure that the standards are maintained.

There is a potential gain of R477,090.00 from the TIG and operational costs annually for the Department of Industrial Engineering. To date the throughput has increased from 8% to 23% in 2012, which represents savings of R474,335 annually from the TOG as per the DHET guidelines. Although the department throughput hasn’t reached the desired rate of 30%, if each subject throughput can increase by 5% for the next three years, the department will be on target by 2016. A subject dashboard system was developed to indicate when a subject’s throughput is becoming a bottleneck. Taken from the network function in Chapter 6, Section 6.2.4.2, this dashboard will assist the department HoDs and lecturers to make quick decisions to support students when their performance is not adequate, enabling them to assign resources for intervention as required. The control plan document as indicated in Figure 8.1 was developed and is a live document which indicates all possible failures which could occur in the process. For each of these failures controls or monitoring techniques are implemented to ensure that the process remains within the desired parameters for it to function effectively. This document is reviewed after each semester to ensure that its controls are still relevant. Process audits were performed, starting from the study guide, subject files and class visits to ensure that the quality of teaching and learning is maintained.

To ensure effective continuous improvement, all improvements which are placed in the system are required to be standardised by including them in a standard study guide, which is placed on myTUTor where all students and lecturers have access to it. The department also maintains a myTUTor page where all documents, communication and lessons learned are kept for record purposes. Since the process improvements resulting from this project were sustained and have been proven to be effective, the next step is to roll out the solution, related to a change in teaching and learning techniques, to another department and assess the results. It is clear that the LSS problem-solving methodology can be used to improve engineering education processes, and that the same methodology can be applied in other departments as well. If these departments do not increase their subject throughput, the chances that the faculty throughput will increase are minimal. Achieving this will require a collaborative effort among all departments within the faculty.

9.7 Summary
This chapter has provided the details of the findings of the investigations. To sum up the different lines of investigation that had been followed throughout the research, it can be stated that throughput was mostly negatively affected by problems with respect to the following:

- student funding
- time students spent familiarising themselves with study content, either in class or whilst studying on their own
- staff to student ratio
- the quality of lecturers, availability of lecturers and availability of supporting learning material.

The next chapter will focus on drawing conclusions and outlining recommendations concerning activities which the faculty could put in place to remedy the present problems.
Chapter 10: Conclusion and Recommendations

10.1 Introduction

In Chapter 1 the research problem of this study was presented. The aim of the study was to develop and apply a comprehensive LSS framework to the engineering education process, to identify where scarce resources should be focused in order to obtain optimal throughput improvements using a unified systematic approach applicable to all disciplines and to use simulation to determine the impact of the key variables on the throughput.

The following research questions were asked:

- Can a LSS framework for engineering education be developed and applied?
- Can this methodology be used to identify where scarce resources can be focused in order to achieve a maximum throughput increase?
- Can this methodology be used as a unified systematic approach for throughput improvement in engineering disciplines?

The findings of this research demonstrated that the LSS framework for engineering education was developed and applied from Chapter 4 to Chapter 8 of this study. The detailed framework also indicated how LSS can be used to identify where scarce resources can be applied in order to achieve maximum throughput. The use of the network function and RTY in Chapter 6 enabled the researcher to develop a model which enhances the easier identification of subjects at critical paths on which scarce resources can be focused. Improving this subject’s throughput will result in the overall enhanced throughput in the programme. Furthermore this methodology can be used by other disciplines as a systematic way to improve throughput. The methodology was applied in the Electrical and Mechanical Engineering disciplines and it indicated progress, even though it was not implemented fully in those programmes. This achievement validated the possibility that LSS can be successfully applied to engineering disciplines.

The study indicated that it is possible to utilise an industry based solution in higher education even though certain aspects must be adapted to ensure the efficient implementation of the tools.
10.2 Conclusions

10.2.1 Conclusion on Research Question 1: Can a LSS framework for engineering education be developed and applied?

Adapting LSS tools to fit engineering education enabled the researcher to develop and apply LSS. While developing the framework it was clear that not all tools which are applied in a manufacturing context are applicable to the engineering education process. Tools which were deemed to be not applicable were excluded from the framework and application thereof.

The following tools were utilised in this framework per phase:

- Define phase: business case, problem statement, goals formulation, scope definition, primary and secondary metrics, high-level process flow and SIPOC analysis
- Measure phase: detailed process flow, measurement system analysis, data collection, cost of poor quality and sigma level
- Analyse phase: logistic regression, factor analysis, hypothesis testing, 2 sample T-test, Box Plots and cause and effect analysis
- Improve phase: casual loop using Vensim and simulation using Stella
- Control phase: control plan, monitoring plan and review of results.

The framework developed using these tools are efficient and it only utilised tools applicable to service the process. The developed framework was validated by applying it to a real-life engineering education problem. In Chapter 4 to Chapter 8 of this study the application of the framework was demonstrated. It was found that the application to the engineering problem provides positive results since the throughput in Industrial Engineering increased from 14% to 23%. This was a significant improvement for a higher education process since the process has long cycle duration.

The overall objective to develop and apply the LSS framework was met and the sub-problem was answered. It was proven that LSS can successfully be applied to an engineering education process.

10.2.2 Conclusion on Research Question 2: Can this methodology be used to identify where scarce resources can be focused in order to get maximum throughput increase?

In Chapter 6, the utilisation of LSS tools, namely network function and RTY, resulted in the identification of subjects which are on a critical path for the Industrial Engineering programmes. These results will enable departments to focus resources on those subjects which are critical in order to improve the programme and faculty throughput rate. Further analysis of the subjects identified indicated that variables related to time spent studying have a major impact on students’ progress.
These variations were then used as inputs to the improve phase to ensure that solutions are identified and implemented.

A proposed solution for increasing student engagement on the subjects which are on a critical path, resulted on the throughput increase for the QAS201T programme from 49% to 67% from 2010 to date. It is therefore concluded that if this approach is applied to other programmes, significant improvements can be realised.

10.2.3 Conclusion on Research Question 3: Can the LSS methodology be used as a unified systematic approach for throughput improvement in engineering disciplines?

The LSS methodology can be used to improve throughput within the engineering education process. This study has illustrated how LSS can be applied within engineering education from the define phase to the control phase. Furthermore, the study indicated that the methodology can be integrated with the university systems. The data collection and analysis of the RTY can easily be done by integrating it with the university data collection system. LSS methodology can be applied in any engineering education discipline since the tools are applicable to any process improvement effort. The results of its implementation in Mechanical and Electrical Engineering indicated that the tools can be utilised in any engineering education programmes.

In the improve phase this study outlined how LSS can be integrated with other system improvement tools like simulation. Systems like Vensim and Stella were used to model the engineering education systems and variables which affect processes.

The results indicated that if throughput needs to be improved, student engagement in their work during the contact week needs to be improved. This refers to time spent studying, in group activities, homework and assignments, which is confirmed in the findings in Chapter 6, which state that time spent studying is the main determinant of student progress. Simulation results indicated that there will be a significant shift in graduation numbers, should student engagement be improved or reduced. The sensitivity analysis indicated that 137 more students can graduate if student engagement is increased from 20 to 40 hrs a week. These results demonstrate that LSS can be used as a systematic unified methodology for throughput improvement in engineering education. Variables which affect student progress can be identified and proposed solutions can be simulated to determine optimum solutions and the implementation thereof. In order for this methodology to be successfully
implemented in all engineering disciplines and sustained, the recommendations in the next section were suggested.

10.3 Recommendations for TUT FoEBE

In Chapter 6, the survey identified factors affecting students’ performance which may be grouped into aspects related to academic schedule, adaptation to learning environment and aspects of the learning and teaching environment. This was validated by the results of hypothesis testing carried out in the analyse phase. In the improve phase, discussed in Chapter 7, the results indicated that if throughput needed to be improved, student engagement in their work during the contact week would likewise need to be improved. This speaks of time spent studying, in group activities, doing homework and assignments. Simulation results indicated that there would be a significant shift in graduation numbers should student engagement be improved or reduced. The sensitivity analysis indicated that 137 more students would be able to graduate if student engagement is increased from 20 to 40 hours a week.

In order to enhance the improvements and to ensure that the faculty as a whole gains from this initiative, it is recommended that the following intervention be applied to all departments as it is related to improving student engagement, financial aid, staff to student ratio and staff quality. Below is a brief explanation of solutions related to these variables.

10.3.1 Student engagement

Studies by Felder and Silverman (1988) and Litzinger et al. (2007) indicated that there are many ways in which students learn: by hearing and seeing; reflecting and acting; reasoning logically and intuitively; memorising, visualising, drawing analogies and building mathematical models; steadily and in fits and starts.

Therefore, engineering lecturers will be obliged to adopt their teaching style to meet the needs of these students or else their programmes will record a low throughput rate and many dropouts, while class attendance will be poor.

With this in mind, the way forward to increasing student engagement is that first, the lecturers must adopt other ways of teaching rather than the traditional chalk and board method as outlined by Felder and Silverman (1988) and Felder et al. (2000) as a reception and processing information type of learning. Their suggestions are summarised in Table 10.1
### Table 10.1: Learning and teaching styles

<table>
<thead>
<tr>
<th>Preferred Learning Style</th>
<th>Corresponding Teaching Style</th>
</tr>
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<tbody>
<tr>
<td>Sensory</td>
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<tr>
<td>Intuitive</td>
<td>Abstract</td>
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<tr>
<td>Visual</td>
<td>Visual</td>
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<tr>
<td>Global</td>
<td>Global</td>
</tr>
</tbody>
</table>

Source: Felder and Silverman (1988)

For a lecturer to be able to reach all students in a class, additional aid is required. Felder and Silverman (1988) emphasised that it is not necessary to use all these styles in one session, however, successful instructors need to vary their teaching methods regularly in order to reach all students in class. They also indicated that the trick is to use computer assisted instruction and not to fill every minute of the class lecturing and writing on the board, but to provide students with activities that allow them to learn by themselves, in class.

In their study concerning the future of engineering education, using a teaching style that works, Felder et al. (2000) report that in order to reach students and to produce graduates who are relevant to today’s needs, they recommend that the lecturer must formulate and publish clear course objectives, balance concrete and abstract information, promote active learning in class, not shy away from experimentation, use cooperative learning and give challenging but fair tests. From this study, it is clear that in order for the student engagement aspect to be increased, the onus is on the engineering education lecturers to ensure that their teaching styles meet the students’ learning styles. In the study by Rugarcia et al. (2000), the emphasis was on getting away from the traditional way of teaching in order to produce future engineers which are relevant to the social environment. To do this might need
additional support which is currently provided through e-learning activities. The introduction of e-learning resources gives lecturers the opportunity to increase student engagement. Nora and Snyder (2008) outline that the use of technology in higher education was motivated by one goal, improving student performance, course completion goals and degree attainment. The move in the USA was based on the fact that the majority of students were exposed to computers before they even entered universities. The study by Nora and Snyder (2008) established that there is a positive relationship between students utilising technology and students’ involvement in educational practices which amount to different types of student engagement.

In South Africa, e-learning has its own challenges, particularly because the majority of the students do not have computer access and do not become computer literate while they are in high school. Although this situation is gradually changing, the truth is that students cannot even pay their tuition fees and thus do not have money to buy laptops and internet connectivity. Studies by Halse and Mallinson (2011) and Hendrik and Serfontein (2004) demonstrated that, although the implementation of e-learning activities can improve student engagement, consideration must be given to the environment in which students find themselves. Institutions will have to invest to enable students to gain access to e-learning facilities in South Africa. TUT has invested significant amounts of money in e-laboratories and wireless connections within the FoEBE to increase student access. Lecturers now need to exploit these facilities and new teaching styles in order to increase the students’ academic performance.

10.3.2. Financial aid
A lack of financial support for students has been cited by many authors as a factor contributing to inadequate student academic performance. For this variable to be addressed, the faculty must seek additional financial support for students, bursaries from private organisations, and non-profit organisations, while government institutions must be solicited in order to increase bursary portions for the faculty. The second suggestion is to screen students during the selection phase and ensure that only students with potential financial support are admitted in the faculty. This methodology, however, will not succeed particularly since the university receives funding from the DHET and the mandate of the government at this point in time is to increase university access especially for disadvantaged students.

The former is currently impossible to implement. Therefore the faculty needs to seek additional financial support for students in order to improve this variable. If this is not a viable option, the faculty
can still focus on the student engagement variable since this variable requires resources which are already available and is easier to implement than soliciting funding.

### 10.3.3 Staff to student ratio

For lecturers or professors to be able to engage students effectively and give them attention, the lecturer to student ratio will have to be reduced. Although studies indicated that large groups can be handled effectively through the use of technological aids and additional assistance, student contact is still a major issue where South African students are concerned. As already noted, the majority of them have not lived by themselves previously and due to the gaps in high school curricula, very few are prepared for university, as argued by Scott et al. (2007). It is therefore important that institutions put mentoring activities in place to guide these students, particularly during their first year at the university (Campbell and Fuqua, 2008, Campbell and Campbell, 1997, Mangold et al., 2002, Santos and Reigadas, 2005). A small group of students is easy to reach, mentor and build good lecturer to student relationships with. The current drive by lecturers and students to utilise myTUTor will also assist with this issue. Using computers to serve as an interface between students and lecturers is starting to gain momentum, although more work still needs to be done.

### 10.3.4 Staff quality

It is critical that the faculty must assess staff quality regularly in order to maintain the quality of the programmes it offers. Since, as remarked earlier, academic staff operate in an environment where they are trusted to do their work with minimal supervision, it is important to do ad hoc assessments to ensure that staff quality remains on par with the expected university standard. A control plan guiding activities to be monitored to ensure the process parameters are always adhered to is important for the sustainability of the improvements. Lecturer quality has a direct relationship to throughput. When lecturer quality increases, student engagement increases and this results in a maximised increase in throughput. The simulation model indicated that if lecturer quality decreases by 20% and funding is left at its current level, there will be more than a 200% decrease in throughput, indicating the direct impact of lecture quality on throughput. For this study, it was found that if lecturers alter their teaching style from traditional teaching styles to the styles outlined by Felder and Silverman (1988), it may be anticipated that lecturer quality will improve. It is recommended that lecturers are encouraged to adopt the proposed teaching styles which will accommodate students’ learning styles. As lecturer quality improves, so will throughput.
10.3.5 Process monitoring and improvements
The university has a student tracking system known as the Higher Education Data Analysis (HEDA), which monitors students’ progress throughout the semester. The current system does not encompass a real time dashboard which would enable the identification of bottleneck subjects. A recommendation has therefore been made to modify the current system and incorporate a real time dashboard system which will monitor subjects continuously, combined with the current activities being monitored by the HEDA system.

10.4 Recommendations for future work
It is recommended that future research investigates the mathematic formulation of the model from RTY calculations and the network function which the faculty could use to determine what the impact of the one subject throughput increase is on the programme throughput and ultimately, what the impact on the faculty throughput is. This model is essential to determine the constraint which is placed on a programme as the result of having subject prerequisites, particularly those in the critical path of the programme.

Further study could determine exactly how much throughput improvement is needed per subject in order to improve the programme throughput and precisely how much of the programme throughput rate improvement must be realised before the faculty throughput rate improves. This will also ensure that resources are efficiently allocated throughout the faculty. This model can then be linked to the automated dashboard system connected to the Integrated Tertiary Software (ITS) system measuring students’ performance, as was proposed in the control phase, to automatically and rapidly identify students not meeting the required throughput rate in order to maintain, or improve, the faculty throughput rate.

Furthermore, automated feedback loops may be built into a system which will allow management to react to key variables which are not meeting standard operating procedures, thereby ensuring the possibility of quick responses, permitting problems to be addressed before they become severe.
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**Appendix A: DMAIC Project Charter**
### Project Chartter

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<th>Resource Plan</th>
<th>General Information</th>
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### Project Overview

**Problem Statement:**

The current throughput rate for the Engineering and Built Environment Faculty in TUT is 14%; this is very low for a third world country and it affects the viability of the faculty.

**Goal Statement:**

To improve throughput from 14% to at least 50% by the end of 2016; this will increase the sigma level from 1.6 to 3 sigma level.

**Project Scope:**

The project will focus on the Faculty of Engineering and the Built Environment; the particular problem to be solved will be the subject failure rate.

**Project Plan** (key dates):

The project started in January 2010, is expected to end in December 2012.
Resources/Team Members:
Grace Kanakana       BB
Prof Ben van Wyk     Sponsor
Toit de Beer         Quality
Zoe Bersman          Student
Louise Banneker      HoD Mechanical
Gift Nenzhelele      Lecturer

Expected Benefits (target savings, DPMO reduction): improve throughput by 36%, which means each department must improve throughput by at least 5%.

Signatures

Champion ___________________________  Process Owner ___________________________
Black Belt __________________________
Date _______________________________
Appendix B: Invitation to Participate in Research

23 August 2010

Dear Sir/Madam

THE STUDY: LEAN SIX SIGMA FRAMEWORK TO IMPROVE THROUGHPUT IN UNIVERSITY OF TECHNOLOGY (TUT)

The Faculty of Engineering and Built Environment is conducting a study in order to determine factors affecting student’s graduation rate and dropout rate. The study intends to identify factors and implement measures to improve throughput.

You are part of the sampled students to participate in this study; the Faculty will appreciate it if you can take time off your busy schedule and help us to build a world class Faculty as per our vision statement.

The information you have provided will be treated in confidence, in order to validate this, we don’t want you to disclose your identity, however we ask that you complete the survey as honestly as possible.

After completion of the questionnaire, you can e-mail it to the following address kanakanamg@tut.ac.za or send it to the following address:

Tshwane University of Technology
Department of Industrial Engineering
Building 3-303
Private Bag X680
Pretoria
0001
The due date for the completion of the survey is Monday, the 20th of September 2010. Please ensure that you complete and send the questionnaire before the end of business day.

Yours Sincerely

G KANAKANA
(Acting) HOD: INDUSTRIAL ENGINEERING (PROJECT LEADER)
BUILDING 3-303B
TEL: (012) 382-5711
Appendix C: Research Participation Consent form for Ethics Approval

INFORMATION LEAFLET AND INFORMED CONSENT

PROJECT TITLE: LEAN SIX SIGMA FRAMEWORK TO INCREASE UoT THROUGHPUT

Primary investigator: Ms G.M. Kanakana, MBA, Department of Industrial Engineering, Tshwane University of Technology, Pretoria

Supervisor leader: Prof JH Pretorius, PhD, Department of Engineering Management, University of Johannesburg, Johannesburg

Co-supervisor: Prof B van Wyk, PhD, Dean of Engineering and the Built Environment, Tshwane University of Technology, Pretoria

Dear Research participant,

You are invited to participate in a study that forms part of my formal PhD in Engineering Management Studies. This information leaflet will assist you in deciding whether you would like to participate or not. Before you agree to take part, you should fully understand what is involved. Please make sure you understand all the aspects of the study before you agree to take part.

WHAT IS THE STUDY ALL ABOUT?
The purpose of the study is to identify factors leading to low throughput in the Faculty of Engineering and the Built Environment, and to design systems or interventions which can help the faculty to solve the problem.

For the purpose of this study, throughput is defined as percentage of students graduating in record time for undergraduate studies.

Currently about 1/4 of students entering undergraduate studies in Engineering and the Built Environment graduate within 3 years, 2/4 drop out, and the remaining few graduate in 6 years’ time.

WHAT WILL YOU BE REQUIRED TO DO IN THE STUDY?

If you decide to take part in the study, you will be required to:

Sign this informed consent form
Attend a 10 minutes interview within the Department of Industrial Engineering. The purpose of this interview is to validate the research instrument and to ensure that all aspects which can lead to a low throughput rate have been accounted for.
Complete a set questionnaire. You will be asked to respond to questions regarding your academic performance while studying at TUT. You will complete the questionnaire at your own pace and in your time. It should not take more than 30 minutes to complete it.

ARE THERE ANY CONDITIONS THAT MAY EXCLUDE YOU FROM THE STUDY?

No exclusions

WHAT ARE THE RISKS INVOLVED IN THIS STUDY? OR CAN ANY OF THE STUDY PROCEDURES RESULT IN PERSONAL DISCOMFORT OR INCONVENIENCE?

Interviews: In the interview you will be sharing emotionally sensitive details about yourself. This process of self-revelation means that you will have to recall emotions, thoughts and actions regarding your experience which could be traumatic for you. Therefore, arrangements have been made with the counsellors at the Student Support Services for you to visit, free of charge, should you want to talk to one of them for professional therapy.
**Questionnaires:** The study and procedures involve no foreseeable physical discomfort or inconvenience to you or your family.

**WHAT ARE THE POTENTIAL BENEFITS THAT MAY RESULT FROM THE STUDY?**

The benefits of participating in this study are:
You will make a contribution towards improving the Faculty of Engineering and the Built Environment and the future generation of engineers in South Africa.

You will be invited to attend an information session where the results of the study will be discussed.

**WILL YOU RECEIVE ANY FINANCIAL COMPENSATION OR INCENTIVE FOR PARTICIPATING IN THE STUDY?**

Please note that you **will not** be paid to participate in the study.

**WHAT ARE YOUR RIGHTS AS A PARTICIPANT IN THIS STUDY?**

Your participation in this study is entirely voluntary. You have the right to withdraw at any stage without any penalty or future disadvantage whatsoever. You don’t even have to provide any reason/s for your decision. Your withdrawal will in no way influence your academic performance and relationship with the researcher or the faculty members.

**HOW WILL CONFIDENTIALITY AND ANONYMITY BE ENSURED IN THE STUDY?**

All the data that you provide during the study will be handled confidentially. This means that access to your data will be strictly limited to the researcher, the supervisors of the study and the designated examiners (appointed by University of Johannesburg). Also, your data and personal information will be kept and stored in a confidential format which will only be accessible to the researcher.

**IS THE RESEARCHER QUALIFIED TO CARRY OUT THE STUDY?**

The researcher is an adequately trained and qualified researcher in the study fields covered by this
research project, specifically in Lean Six Sigma methodology and Industrial Engineering.

HAS THE STUDY RECEIVED ETHICAL APPROVAL?

Yes. The Faculty of Engineering and the Built Environment Research Committee has approved the formal study proposal.

WHO CAN YOU CONTACT FOR ADDITIONAL INFORMATION REGARDING THE STUDY?

The primary investigator, Ms Grace Kanakana, can be contacted during office hours at Tel (012) 382-5711, or on her cellular phone at 076 499 0489. The study supervisor, Prof JH Pretorius, can be contacted during office hours at Tel (011) 559-3377. Should you have any questions regarding the ethical aspects of the study, you can contact the chairperson of the TUT Research Ethics Committee, Dr WA Hoffmann, during office hours at Tel (012) 382-6265/46.

DECLARATION: CONFLICT OF INTEREST

There is no conflict of interest resulting from the study funding agent or the two universities involved in this study.

A FINAL WORD

Your co-operation and participation in the study will be greatly appreciated. Please sign the informed consent underneath if you agree to participate in the study. In such a case, you will receive a copy of the signed informed consent from the researcher.

CONSENT

I hereby confirm that I have been adequately informed by the researcher about the nature, conduct, benefits and risks of the study. I have also received, read and understood the written information. I am aware that the results of the study will be anonymously processed into a research report. I understand that my participation is voluntary and that I may, at any stage, without prejudice,
withdraw my consent and participation in the study. I had sufficient opportunity to ask questions and of my own free will declare myself prepared to participate in the study.

Research participant’s name: ____________________________(Please print)

Research participant’s signature: __________________________

Date: ________

Researcher’s name: ____________________________(Please print)

Researcher’s signature: __________________________

Date: ________
Appendix D: Informed Consent Form

Faculty of Engineering and the Built Environment

Department: Industrial Engineering

INFORMED CONSENT FORM

(Form for research subject's permission)

(Must be signed by each research subject, and must be kept on record by the researcher)

Title of research project: LEAN SIX SIGMA FRAMEWORK TO IMPROVE THROUGHPUT IN UNIVERSITY OF TECHNOLOGY (TUT)

I ........................................ hereby voluntarily grant my permission for participation in the project as explained to me by ........................................

The nature, objective, possible safety and health implications have been explained to me and I understand them.

I understand my right to choose whether to participate in the project and that the information furnished will be handled confidentially. I am aware that the results of the investigation may be used for the purposes of publication.

Upon signature of this form, you will be provided with a copy.

Signed: _________________________ Date: _______________

Witness: _________________________ Date: _______________

Researcher: _________________________ Date: _______________
Appendix E: Questionnaire

23 August 2010

Dear Sir/Madam

THE STUDY: LEAN SIX SIGMA FRAMEWORK TO IMPROVE THROUGHPUT AT THE TSHWANE UNIVERSITY OF TECHNOLOGY (TUT)

The Faculty of Engineering and the Built Environment is conducting a study in order to determine factors affecting students’ graduation rate within the Engineering field. The study intends to identify factors and implement measures to improve the current status. This will be done in partial fulfilment of the Doctorate in Philosophy of Engineering Management at the University of Johannesburg.

Since you are one of the sampled students to participate in this study; the Faculty will appreciate it if you can take time off your busy schedule and help us to build a world-class Faculty as per our vision statement by filling in the questionnaire.

All information supplied will be treated with utmost confidentiality. The information provided in the completed questionnaires will be used for the purpose of the research only, and will not be made available to any party or organisation for other purposes.

Completed questionnaires can be e-mailed to kanakanamg@tut.ac.za, or can be forwarded to this address: Industrial Engineering Department, Building 3 Room 303B, Private Bag X680, Pretoria, 0001.

Should you choose to return the questionnaire via e-mail, please note that your anonymity cannot be guaranteed due to TUT official policy which allows the screening of e-mail messages within the TUT domain. If you wish to remain completely anonymous, send the completed questionnaire via post or drop it at Industrial Engineering Department, Building 3 Room 303B or fax it to (012) 382 4847.
For any TUT ethics-related enquiries – Dr WA Hoffmann, the chairperson of the Ethics Committee, can be contacted at tel. 012 3826246/65

Yours sincerely

G KANAKANA
(Acting) HOD: INDUSTRIAL ENGINEERING (PROJECT LEADER)
BUILDING 3-303B
TEL: 012 3825711

SECTION A: BIOGRAPHICAL INFORMATION

Please provide the following biographical information by marking with a tick or filling in the spaces provided.

Male

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195 | Page |
23-25

Older than 25

Which SA province do you come from?

KwaZulu-Natal

Gauteng

Limpopo

Western Cape

Eastern Cape

Mpumalanga

North-West

Northern Cape

Free State

Are your parents working? Yes No
The average income of your parents or legal guardian per annum?

Less than 10 000  1

10 000 - 50 000  2

50 001 - 120 000  3

120 001 - 180 000  4

180 001 - 240 000  5

240 001 - 360 000  6

360 001 -  7

First year of entering the Faculty of Engineering and the Built Environment:

2004  1

2005  2

2006  3

2007  4

2008  5
First degree of study when you entered/joined the Faculty:

………………………………………………………………………………………………………………………………………………
………………………………………………………………………………………………………………………………………………
…………………………

Are you still studying at TUT?            Yes                                  No

If yes, which level are you currently at?

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Indicate to what level did the reasons contribute to you failing the subject (s)?

Level of importance:
1 – Not at all, 2 – Very little, 3 – To some extent and 4 – To a great extent

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3.12 Had a conflict with a lecturer
3.13 Problem with the language of instruction
3.14 No mentorship
3.15 Not enough time to cover work due to semester courses

If you have dropped out of any Engineering and the Built Environment courses, at which level did you drop out?

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If you have dropped out, please indicate your Grade 12 or Standard 10 results on the appropriate box. Please write your grades as per the APS, e.g. Mathematics HG 60% = 4 and SG = 3.

5.1. Mathematics 1

Science 2

English 3

If you have dropped out please indicate to what extent did the following factors contribute to your dropping out?

Level of importance:
1 – Not at all, 2 – Very little, 3 – To some extent, and 4 – To a great extent

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<td>e.g. parents’ ill health, parents pass away, get married</td>
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<td>7.5 Lecturer’s presentation of the subject not clear</td>
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<td>Time frame of the course too short</td>
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<td>HoD’s interaction with students</td>
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<td>7.8</td>
<td>Departmental Administrator’s interaction with students</td>
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<td>7.9</td>
<td>Dean’s interaction with students</td>
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| 7.10 | Peer pressure:  
e.g. pressure from friends, pressure from relationships |
| 7.11 | Pregnancy |
| 7.12 | Not fitting into the institution’s culture:  
e.g. involvement in student life activities, adjusting to tertiary life without parents’ supervision |
| 7.13 | Not coping with the work required |
| 7.14 | Conflict with a lecturer |
| 7.15 | Transport problems |
| 7.16 | Your ill health |
| 7.17 | Did not understand the work |
| 7.18 | Academic exclusion |

State other reasons if available: ………………………………………………………………………………………………….

If you have not dropped out please indicate factors which can lead you to dropping out

Level of importance:
1 –Not at all, 2 –Very little, 3 – To some extent, and 4 – To a great extent

| 8.1 | Lack of finances |
| 8.2 | Family pressures:  
e.g. parents’ ill health, parents pass away, get married |
| 8.3 | Lecturer’s interaction with students in class |
| 8.4 | Lecturer’s interaction with students during consultation |
| 8.5 | Lecturer’s presentation of the subject not clear |
| 8.6 | Time frame of the course too short |
| 8.7 | HoD’s interaction with students |
| 8.8 | Departmental Administrator’s interaction with students |
| 8.9 | Dean’s office’s interaction with students |
| 8.10 Peer pressure:                          |   |   |   |
| e.g. pressure from friends, pressure from relationships |   |   |   |
| 8.11 Pregnancy                                      |   |   |   |
| 8.12 Not fitting into the institution’s culture    |   |   |   |
| e.g. Involvement in student life activities, adjusting to tertiary life without parents’ supervision |   |   |   |
| 8.13 Not coping with the work required             |   |   |   |
| 8.14 Conflict with a lecturer                      |   |   |   |
| 8.15 Transport problems                            |   |   |   |
| 8.16 Your ill health                               |   |   |   |
| 8.17 Did not understand the work                  |   |   |   |

9. State other reasons if available: .................................................................

10. Before dropping out, did you seek for assistance? Yes  |  No

If your answer is Yes on 10, please tell us what kind of help did you seek

| 11.1. Tutorial support | Yes | No |
| Mentoring              | Yes | No |
| HoD's intervention     | Yes | No |
| Psychological help     | Yes | No |
| Medical support        | Yes | No |
| Dean’s intervention    | Yes | No |
Did you find the help given to you fruitful?

What do you think the Faculty (Dean) of Engineering and the Built Environment should do to prevent students from dropping out?

What do you think the departments (HoDs) should do to prevent students from dropping out?
Appendix F: Interview Guide (Questionnaire Formulation)

THE STUDY: LEAN SIX SIGMA FRAMEWORK TO IMPROVE THROUGHPUT IN UNIVERSITY OF TECHNOLOGY (TUT)

Questions:

Why did the student drop out?
Why did you fail a subject?
How did failing a subject or dropping out impact a student’s life?
What is the student doing currently?
Can the student refer their family members to come study engineering at TUT?
In their opinion, what can the Faculty of Engineering and the Built Environment do to prevent students from dropping out?

Yours Sincerely

G KANAKANA
(Acting) Hod: Industrial Engineering (Project Leader)
Building 3-303B
Tel: (012) 382-5711
Appendix G: Simulation Model Equations

Alum(t) = Alum(t - dt) + (Graduating) * dt

INIT Alum = 0

INFLOWS:

Graduating = Semester_6_Students_1*Graduating_rate

Semester_1__students(t) = Semester_1__students(t - dt) + (New_1st_years - Dropout_1st_SM - Pass_1st_to_2nd) * dt

INIT semester_1__students = 800

INFLOWS:

New_1st_years = (Number_admitted*turnup_rate)

OUTFLOWS:

Dropout_1st_SM = Semester_1__students*dropout_rate

Pass_1st_to_2nd = Pass_rate__1st_to_2nd*semester_1__students

Semester_2__students(t) = Semester_2__students(t - dt) + (pass_1st_to_2nd - pass_2nd_to_3rd - Dropouts_2nd_SM) * dt

INIT Semester_2__students = 600

INFLOWS:

Pass_1st_to_2nd = pass_rate__1st_to_2nd*semester_1__students

OUTFLOWS:

Pass_2nd_to_3rd = Semester_2__students*Pass_rate__2nd_to_3rd

Dropouts_2nd_SM = Semester_2__students*Dropout_rate__S2

Semester_3__students(t) = Semester_3__students(t - dt) + (Pass_2nd_to_3rd - dropout_3rd_SM - Pass_3rd__to_4rth) * dt

INIT Semester_3__students = 300

INFLOWS:
Pass_2nd_to_3rd = Semester_2__students*Pass_rate__2nd_to_3rd

OUTFLOWS:

Dropout_3rd_SM = Semester_3__students*Dropout_rate__S3
Pass_3rd___to_4rth = Semester_3__students*Pass_rate__3rd_to_4th

Semester_4_students(t) = Semester_4_students(t - dt) + (Pass_3rd___to_4rth - Pass_4th___to_5th - Dropout_4th_SM) * dt

INIT semester_4_students = 0

INFLOWS:

Pass_3rd___to_4rth = Semester_3__students*Pass_rate__3rd_to_4th

OUTFLOWS:

Pass_4th___to_5th = Semester_4_students*Pass_rate__4th_to_5th
Dropout_4th_SM = Semester_4_students*Dropout_rate__S4

Semester_5_Students(t) = Semester_5_Students(t - dt) + (Pass_4th___to_5th - Pass_5th___to_6th - Dropout_5th_SM) * dt

INIT Semester_5_Students = 0

INFLOWS:

Pass_4th___to_5th = Semester_4_Students*Pass_rate__4th_to_5th

OUTFLOWS:

Pass_5th___to_6th = Semester_5_Students*pass_rate__5th_to_6th
Dropout_5th_SM = Semester_5_Students*Dropout_rate__S5

Semester_6_Students_1(t) = semester_6_Students_1(t - dt) + (Pass_5th___to_6th - Graduating - Dropout_6th_SM) * dt

INIT semester_6_Students_1 = 0

INFLOWS:

Pass_5th___to_6th = Semester_5_Students*pass_rate__5th_to_6th

OUTFLOWS:
Graduating = semester_6_Students_1*Graduating_rate
Dropout_6th_SM = semester_6_Students_1*dropout_rate_S6
Academic_Exclusion_rate = Impact_time_studying*.5
Academic_Exclusion_rate_S2 = impact_time_studying_S2*.5
Academic_Exclusion_rate_S3 = impact_time_studying_S3*.5
Academic_Exclusion_rate_S4 = impact_time_studying_S4*.5
Academic_Exclusion_rate_S5 = 0.001
Academic_Exclusion_rate_S6 = 0.001
Assessment_styles = 0.8
Average_self_study_hrs_per_week = 20
Average_self_study_hrs_per_week_S2 = 20
Average_self_study_hrs_per_week_S3 = 30
Average_self_study_hrs_per_week_S4 = 30
Average_student_fees = 21000
Average_student_fees_S2 = 21000
Average_student_fees_S3 = 21000
Average_student_fees_S4 = 21000
Average_student_fees_S5 = 21000
Average_student_fees_S6 = 21000
Carrying_capacity = 11000
Classroom_environment = 1
Contact_hrs_per_week = 40
Contact_hrs_per_week_S2 = 40
Contact_hrs_per_week_S3 = 30
Contact_hrs_per_week_S4 = 30
Current enrolment =
Semester_1_students+Semester_2_students+Semester_3_students+Semester_4_students+Semester_5_students+Semester_6_students

Desired enrolment = 12

Dropout rate = academic exclusion rate + financial exclusion rate + voluntary exclusion rate

Dropout rate_S2 =
Academic__Exclusion_rate_S2 + Financial__exclusion_rate_S2 + Voluntary__exclusion_rate_S2

Dropout rate_S3 =
Academic__exclusion_rate_S3 + Financial__exclusion_rate_S3 + Voluntary__exclusion_rate_S3

Dropout rate_S4 =
Academic__exclusion_rate_S4 + Financial__exclusion_rate_S4 + Voluntary__exclusion_rate_S4

Dropout rate_S5 =
Academic__exclusion_rate_S5 + Financial__exclusion_rate_S5 + Voluntary__exclusion_rate_S5

Dropout rate_S6 =
Academic__exclusion_rate_S6 + Financial__exclusion_rate_S6 + Voluntary__exclusion_rate_S6

Financial__exclusion_rate = (Students__in_need- Number__students_funded)/number__of_students__in_the_system

Financial__exclusion_rate_S2 = (Students__in_need_S2- Number__students_funded_S2)/number__of_students__in_the_system

Financial__exclusion_rate_S3 = (Students__in_need_S3- Number__students_funded_S3)/number__of_students__in_the_system

Financial__exclusion_rate_S4 = (Students__in_need_S4- Number__students_funded_S4)/number__of_students__in_the_system

Financial__exclusion_rate_S5 = (Students__in_need_S5- Number__students_funded_S5)/number__of_students__in_the_system

Financial__exclusion_rate_S6 = (Students__in_need_S6- Number__students_funded_S6)/number__of_students__in_the_system
Financial\_exclusion\_rate\_S6 = (Students\_in\_need\_S6 -
Number\_students\_funded\_6) / number\_of\_students\_in\_the\_system

Graduating\_rate = Maximum\_Pass\_rate\_6 * Current\_Student\_Quality\_6

Living\_environment = 1

Maximum\_pass\_rate = 1 - dropout\_rate

Maximum\_pass\_rate\_4 = 1 - dropout\_rate\_S4

Maximum\_pass\_rate\_2 = 1 - dropout\_rate\_S2

Maximum\_Pass\_rate\_5 = 1 - dropout\_rate\_S5

Maximum\_Pass\_rate\_6 = 1 - dropout\_rate\_S6

Maximum\_Pass\_rate\_3 = 1 - dropout\_rate\_S3

non\_bursary\_holders\_fraction = .70

non\_bursary\_holders\_fraction\_S2 = .80

non\_bursary\_holders\_fraction\_S3 = .85

non\_bursary\_holders\_fraction\_S4 = .85

non\_bursary\_holders\_fraction\_S5 = .95

non\_bursary\_holders\_fraction\_S6 = .98

Number\_admitted = MIN(Carrying\_Capacity - Current\_enrolment, Desired\_enrolment)

Number\_of\_staff = 60

Number\_Quality\_Hs\_graduate\_applying\_TUT = 1000

Number\_of\_students\_in\_the\_system =

Semester\_1\_students + Semester\_2\_students + Semester\_3\_students + Semester\_4\_students + Semester\_5\_students + Semester\_6\_students + new\_1st\_years

Number\_students\_funded = Total\_bursary\_value / average\_student\_fees

Number\_students\_funded\_4 = Total\_bursary\_value\_S4 / average\_student\_fees\_S4

Number\_students\_funded\_5 = Total\_bursary\_value\_S5 / average\_student\_fees\_S5

Number\_students\_funded\_6 = Total\_bursary\_value\_S6 / average\_student\_fees\_S6
Number__students_funded_S2 = Total__bursary_value_S2/average_student_fees_S2
Number__students_funded_S3 = Total__bursary_value_S3/average_student_fees_S3
Pass_rate__1st_to_2nd = (1-
Impact_time_studying)*Maximum_pass_rate*student__Learning_environment*Current__student__quality*New_student__quality
Pass_rate__2nd_to_3rd = (1-
Impact_time_studying_S2)*Maximum__pass_rate_2*Student_learning__environment*Current__student__quality_2
Pass_rate__3rd_to_4th = (1-
Impact_time_studying_3)*Maximum__Pass_rate_3*Student_learning__environment_3*Current__student__quality_3
Pass_rate__4th_to_5th = (1-
Impact_time_studying_S4)*Maximum_pass_rate_4*Student_learning__environment_4*Current__student__quality_4
Pass_rate__5th_to_6th = Maximum__Pass_rate_5*Current__student_quality
Salary__scale = 8000
Staff_quality = Assessment__styles*Use_of_myTUTor*Years_of__experience
Staff_student_ratio = Number_of__staff/(Semester_1__students*6)
Staff__student_ratio_2 = Number_of__staff/(Semester_2__students*6)
Staff__student_ratio_3 = Number_of__staff/(Semester_3__students*6)
Staff__student_ratio_4 = Semester_4_students/(Number_of__staff*6)
Students__in_need = Number__of_students__in_the_system*(1-non_bursary__holders_fraction)
Students__in_need_S2 = Number__of_students__in_the_system*(1-
Non_bursary__holders_fraction_S2)
Students__in_need_S3 = Number__of_students__in_the_system*(1-
Non_bursary__holders_fraction_S3)
Students\_in\_need\_S4 = Number\_of\_students\_in\_the\_system*(1-non\_bursary\_holders\_fraction\_S4)

Students\_in\_need\_S5 = Number\_of\_students\_in\_the\_system*(1-Non\_bursary\_holders\_fraction\_S5)

Students\_in\_need\_S6 = Number\_of\_students\_in\_the\_system*(1-Non\_bursary\_holders\_fraction\_S6)

Student\_learning\_environment = Classroom\_environment*Living\_environment*Staff\_quality*Impact\_of\_staff\_student\_ratio_2

Student\_learning\_environment\_3 = Classroom\_environment*Living\_environment*Staff\_quality*Impact\_of\_staff\_student\_ratio_3

Student\_learning\_environment\_4 = Classroom\_environment*Living\_environment*Staff\_quality*Impact\_of\_staff\_student\_ratio_4

Student\_learning\_Environment = Classroom\_environment*Living\_environment*Staff\_quality*Impact\_of\_staff\_student\_ratio

Total\_bursary\_value = 10000000

Total\_bursary\_value\_3S = 10000000

Total\_bursary\_value\_S2 = 10000000

Total\_bursary\_value\_S4 = 10000000

Total\_bursary\_value\_S5 = 10000000

Total\_bursary\_value\_S6 = 10000000

Turnup\_rate = .95

Use\_of\_myTUTor = 0.8

Voluntary\_Exclusion\_rate = 0.05

Voluntary\_Exclusion\_rate\_S2 = 0.025

Voluntary\_Exclusion\_rate\_S3 = 0.01

Voluntary\_Exclusion\_rate\_S4 = 0.01
Voluntary Exclusion rate S6 = 0.001

Years of experience = 0.8

Current student quality =

GRAPH(6*Semester_1__students/Number__of_students__in_the_system)
(0.4, 1.08), (0.6, 1.08), (0.8, 1.05), (1.00, 1.00), (1.20, 0.908), (1.40, 0.836), (1.60, 0.802), (1.80, 0.774), (2.00, 0.756), (2.20, 0.73), (2.40, 0.708)

Current__student__quality_2 =

GRAPH(6*Semester_2___students/Number__of_students__in_the_system)
(0.4, 1.08), (0.6, 1.08), (0.8, 1.05), (1.00, 1.00), (1.20, 0.796), (1.40, 0.621), (1.60, 0.43), (1.80, 0.302), (2.00, 0.214), (2.20, 0.122), (2.40, 0.07)

Current__Student__Quality_3 =

GRAPH(6*Semester_3__Students/Number__of_students__in_the_system)
(0.4, 1.08), (0.6, 1.08), (0.8, 1.05), (1.00, 1.00), (1.20, 0.796), (1.40, 0.621), (1.60, 0.43), (1.80, 0.302), (2.00, 0.214), (2.20, 0.122), (2.40, 0.07)

Current__student__quality_4 =

GRAPH(6*Semester_4_Students/Number__of_students__in_the_system)
(0.4, 1.08), (0.6, 1.08), (0.8, 1.05), (1.00, 1.00), (1.20, 0.796), (1.40, 0.621), (1.60, 0.43), (1.80, 0.302), (2.00, 0.214), (2.20, 0.122), (2.40, 0.07)

Current__student__quality_6 =

GRAPH(6*Semester__6_Students_1/number__of_students__in_the_system)
(0.4, 1.08), (0.6, 1.08), (0.8, 1.05), (1.00, 1.00), (1.20, 0.796), (1.40, 0.621), (1.60, 0.43), (1.80, 0.302), (2.00, 0.214), (2.20, 0.122), (2.40, 0.07)

current__student__quality =

GRAPH(6*Semester_5_Students/Number__of_students__in_the_system)
(0.4, 0.997), (0.6, 0.994), (0.8, 0.976), (1.00, 0.926), (1.20, 0.905), (1.40, 0.886), (1.60, 0.817), (1.80, 0.797), (2.00, 0.778), (2.20, 0.731), (2.40, 0.7)
Impact_of___staff_student_ratio = GRAPH(Staff_Student_ratio)
(0.00, 0.618), (0.005, 0.69), (0.01, 0.748), (0.015, 0.808), (0.02, 0.848), (0.025, 0.888), (0.03, 0.928),
(0.035, 0.952), (0.04, 0.98), (0.045, 0.988), (0.05, 0.995)

Impact_of___staff_student_ratio_2 = GRAPH(staff__student_ratio_2)
(0.00, 0.618), (0.005, 0.69), (0.01, 0.748), (0.015, 0.808), (0.02, 0.848), (0.025, 0.888), (0.03, 0.928),
(0.035, 0.952), (0.04, 0.98), (0.045, 0.988), (0.05, 0.995)

Impact_of___staff_student_ratio_3 = GRAPH(staff__student_ratio_3)
(0.00, 0.618), (0.005, 0.69), (0.01, 0.748), (0.015, 0.808), (0.02, 0.848), (0.025, 0.888), (0.03, 0.928),
(0.035, 0.952), (0.04, 0.98), (0.045, 0.988), (0.05, 0.995)

Impact_of___staff_student_ratio_4 = GRAPH(staff__student_ratio_4)
(0.00, 0.618), (0.005, 0.69), (0.01, 0.748), (0.015, 0.808), (0.02, 0.848), (0.025, 0.888), (0.03, 0.928),
(0.035, 0.952), (0.04, 0.98), (0.045, 0.988), (0.05, 0.995)

Impact_of___staff_student_ratio_3 = GRAPH(staff__student_ratio_3)
(0.00, 0.618), (0.005, 0.69), (0.01, 0.748), (0.015, 0.808), (0.02, 0.848), (0.025, 0.888), (0.03, 0.928),
(0.035, 0.952), (0.04, 0.98), (0.045, 0.988), (0.05, 0.995)

Impact_of___staff_student_ratio_4 = GRAPH(staff__student_ratio_4)
(0.00, 0.618), (0.005, 0.69), (0.01, 0.748), (0.015, 0.808), (0.02, 0.848), (0.025, 0.888), (0.03, 0.928),
(0.035, 0.952), (0.04, 0.98), (0.045, 0.988), (0.05, 0.995)

Impact_time_studying = GRAPH(average_self_study__hrs_per_week/contact_hrs_per__week)
(0.00, 0.614), (0.2, 0.477), (0.4, 0.369), (0.6, 0.257), (0.8, 0.198), (1.00, 0.152), (1.20, 0.102), (1.40,
0.0713), (1.60, 0.0496), (1.80, 0.0124), (2.00, 0.0062)

Impact_time_studying_3 =
GRAPH(average_self_study__hrs_per_week_S3/contact_hrs_per__week_S3)
(0.00, 0.12), (0.2, 0.0936), (0.4, 0.0672), (0.6, 0.0528), (0.8, 0.0444), (1.00, 0.036), (1.20, 0.0276),
(1.40, 0.021), (1.60, 0.0162), (1.80, 0.0084), (2.00, 0.0012)

Impact_time_studying_S2 =
GRAPH(average_self_study__hrs_per_weekS_2/contact_hrs_per__week_S2)
(0.00, 0.22), (0.2, 0.167), (0.4, 0.131), (0.6, 0.0935), (0.8, 0.0748), (1.00, 0.0649), (1.20, 0.0517),
(1.40, 0.0385), (1.60, 0.0297), (1.80, 0.0176), (2.00, 0.00)

impact_time_studying_S4 =
GRAPH(average_self_study__hrs_per_week_S4/contact_hrs_per__week_S4)
New_student__quality = GRAPH(Number_Quality_Hs_graduate_applying_TUT/number_admitted)

(0.00, 0.5), (0.1, 0.522), (0.2, 0.568), (0.3, 0.635), (0.4, 0.723), (0.5, 0.795), (0.6, 0.855), (0.7, 0.91),
(0.8, 0.953), (0.9, 0.982), (1, 0.998)

Voluntary__exclusion_rate_S5 = GRAPH(salary__scale)

(4000, 0.00), (5100, 0.0025), (6200, 0.0065), (7300, 0.011), (8400, 0.014), (9500, 0.0185), (10600,
0.0265), (11700, 0.039), (12800, 0.0495), (13900, 0.0695), (15000, 0.1)
Appendix H: Model Semester 1
Appendix I: Model Semester 2
Appendix J: Model Semester 3
Appendix K: Model Semester 4

<table>
<thead>
<tr>
<th>Number of students in the system</th>
<th>Semester 4</th>
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<tr>
<td>Dropout 4th SM</td>
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<tr>
<td>Number of staff</td>
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</table>

| Impact time studying S4         |            |
| Living environment              |            |
| Classroom environment           |            |
| Staff student ratio 4           |            |
| Maximum pass rate 4             |            |
| Student learning environment 4  |            |
| Contact hrs per week S4         |            |
| Academic exclusion rate S4      |            |
| Non bursary holders fraction S4 |            |
| Number of students in the system|            |
| Students in need S4             |            |
| Number of students funded 4     |            |
| Total bursary value S4          |            |
| Average self study hrs per week S4 |        |
| Average student fees S4         |            |
| Financial exclusion rate S4     |            |
| Voluntary exclusion rate S4     |            |
| Current student quality 4       |            |
| Maximum pass rate 4             |            |
| Staff quality                   |            |

UNIVERSITY OF JOHANNESBURG
Appendix L: Model Semester 5
Appendix M: Model Semester 6

<table>
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<td>Number of students</td>
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<tr>
<td>Graduating rate</td>
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<tr>
<td>Number of students</td>
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<tr>
<td>in the system</td>
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<tr>
<td>Current student</td>
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<tr>
<td>quality</td>
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<td>Financial exclusion</td>
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<tr>
<td>rate</td>
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</tr>
<tr>
<td>Voluntary exclusion</td>
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</tr>
<tr>
<td>Number of students</td>
<td></td>
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<tr>
<td>funded</td>
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<tr>
<td>Students in need</td>
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<tr>
<td>Non bursary holders</td>
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<tr>
<td>fraction</td>
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<td>Total bursary</td>
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<td>value</td>
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<td>Average student fees</td>
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<td>Maximum Pass rate</td>
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<tr>
<td>Academic exclusion</td>
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<tr>
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<td>Number of students</td>
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## Appendix N: National Diploma: Engineering: Industrial

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### Semester 1

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<tr>
<td>EGN101T</td>
<td>Engineering Communication I*</td>
</tr>
<tr>
<td>ETT101T</td>
<td>Electrotechnology I</td>
</tr>
<tr>
<td>MAT171T</td>
<td>Mathematics I</td>
</tr>
<tr>
<td>MDR101B</td>
<td>Mechanical Engineering Drawing I</td>
</tr>
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<td>MHC101T</td>
<td>Mechanics I</td>
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<td>MAT271T</td>
<td>Mathematics II</td>
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<td>MFR201T</td>
<td>Manufacturing Relations II</td>
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<td>MME201T</td>
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<td>PEI111T</td>
<td>Production Engineering: Industrial I</td>
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<td>PEI211T</td>
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**Semester 4**

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<td>Industrial Accounting III</td>
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<td>Industrial Engineering Systems Design II*</td>
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<td>ILE301T</td>
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**Semester 5**

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**Semester 6**

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Appendix O: National Diploma: Engineering: Mechanical

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<td>EGN101T</td>
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<tr>
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<td>MME101T</td>
<td>Mechanical Manufacturing Engineering I</td>
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<td><strong>Semester 2</strong></td>
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<td>FMS211T</td>
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<td>Mathematics II</td>
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<td>MMH211T</td>
<td>Mechanics of Machines II</td>
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<tr>
<td>SMT211T</td>
<td>Strength of Materials II</td>
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<td>TDN201T</td>
<td>Thermodynamics II</td>
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<td>Theory of Machines III</td>
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Plus one of the following subjects:

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### Semester 5

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### Semester 6

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### Appendix P: National Diploma: Engineering: Electrical

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<td>Engineering Science I</td>
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POLICY ON THE ACADEMIC EXCLUSION OF UNDERGRADUATE STUDENTS

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<th>28 March 2011</th>
<th>Name of the owner of the policy</th>
<th>DVC TLT</th>
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<td>Quality Promotion:</td>
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<td>Notification date:</td>
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<td>18 January 2011</td>
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<td>15 March 2011</td>
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Previous version of this policy:
Date issued: 7 April 2004
Date first revision approved by EMC: 27 November 2006
Date second revision approved by Senate:

This policy and its rules, guidelines and procedures replace all previous policy and/or circulars on the academic exclusion of students in terms of unsatisfactory academic progress.

Preamble

In accordance with national policy, it is required of all students to complete their qualification in a period not exceeding double the minimum period allowed for that qualification. (e.g. – the maximum period of obtaining a 3 year National Diploma is 6 years)

1. POLICY

In order to maximise the university’s capacity to deliver qualified alumni to industry, it is the policy of Tshwane University of Technology (TUT) to conduct academic exclusion with an embedded preventative strategy of continuous academic monitoring and intervention.

2. DEFINITIONS
**Academic Development Threshold**
Minimum number of subjects or assessments passed to avoid monitored participation in a structured Academic Intervention programme.

**Academic Exclusion Threshold**
Minimum number of credits earned per academic year to avoid Academic Exclusion.

**Academic Intervention**
Refers to any programme or supportive or developmental action prescribed (compulsory) or recommended (voluntary) by the University for the promotion of academic success. Academic interventions may be on group or individual basis.

**Academic Exclusion**
Students that will be excluded from further studies in academic programmes at TUT for a period of two years due to unsatisfactory academic performance as defined by the academic exclusion threshold. Students may be referred for professional career counselling on alternative or renewed career planning.

**Academic Performance**
The relative success or failure of a student to pass the prescribed academic programme for undergraduate study within a specified academic period of an approved programme which the student is registered for at TUT.

**Faculty Academic Exclusions Appeals Committee (FAEAC)**
The departmental committee that evaluates the appeals of academically excluded students.

**Composition of panel:**

**a) Pretoria, Soshanguve and Garankuwa Campuses**
- Dean of the Faculty or secundus
- Heads of Department;
- 1 x senior academic per academic department;
- Assistant Registrar: Student Administration (or representative of the Registrar’s Office);
• Faculty administrator/secretary from the faculty who will be responsible for the taking of the minutes (prescribed template – addendum)
• 1x fully registered (not excluded) student representative council member.

b) Distant campuses:
• Campus Director or secundus
• Heads of Academic sections
• 1 x senior academic per department
• 1 x representative from academic administration
• 1 x administrator who will be responsible for the taking of the minutes (prescribed template – addendum)
• 1 x fully registered (not excluded) member of the student representative council.

Readmission to Studies
Permission is granted to a student by the Faculty (FAEAC) to continue with studies, thereby allowing a student to re-register for the next academic term.

Condition of readmission refers to the stipulations or requirements set by the FAEAC for the readmission of a student. This may include referral for academic intervention, career counselling, performance level required, limited subject load or any relevant condition that will be recorded and communicated to the student during the meeting.

TUT Student Tracking System (TUT-STS)
Refers to the integrated University student monitoring system that provides facility to regularly calculate and monitor student progress and issue early alerts to students at risk.

Student in this policy refers to all undergraduate students registered at TUT for any of the official modes of delivery.

Academic Exclusion template refers to the prescribed format for recordkeeping (addendum to this Policy)

3. RULES
3.1 UNDERGRADUATE STUDENTS

3.1.1 All students are required to successfully complete their studies within a period not exceeding active registration for twice the minimum number of years allowed to complete such programmes. Refer to Rule 3.1.1.1(c) (i). In the general rules and regulations.

3.1.2 In order to assist TUT to identify and help students before they are excluded, academic staff will have access to a system of continuous monitoring and risk management. This system will generate a record of alerts (timeous warnings of poor performance) to the student and all intervention data will be recorded. This record may be used as evidence for or against the candidate during an exclusion review.

3.1.3 A student may be excluded based on evidence (proof) of poor class and or tutorial attendance (refer TUT Policy on Class Attendance).

3.1.4 A student, who has, despite the academic intervention, failed to acquire the necessary credits and fell below the academic exclusion threshold, will then be excluded according to the procedures set out in this policy.

3.1.5 Students may submit an appeal for readmission to the Department giving full evidence of aspects to be considered,

a) The Head of Department (HoD) will receive, monitor and collate all appeals to be submitted. The committee will not accept direct submissions and only those submitted via the HoD will be accepted for the agenda. The agenda will close strictly on the announced date with no ongoing considerations.

b) Students may only approach the Department (lecturer and HoD) in logging an appeal and no personal contact or petition to the chairperson of the FAEAC (Dean/secundus) prior to the meeting is allowed. The prescribed form (Appendix C of this Policy) should be submitted.

3.1.6 The Department will prepare a full record of Departmental appeals and recommendations (also utilising student tracking record where relevant as valid information for or against the appeal) for the sitting of the FAEAC.
3.1.7 The FEAEC will utilise the guideline document – Appendix: A. Contents of this guideline to committees to be confirmed annually at the October meeting of the Academic Committee will serve as the baseline for interpretation and decisions.

3.1.8 The FAEAC will make a final decision to be communicated to the student and recorded onto the prescribed template (Appendix B) to be submitted as an official record of decisions to the Assistant Faculty Registrar. The Assistant Faculty Registrar will officially communicate outcomes to the students and submit for recording/update on the student tracking system.

3.1.9 A student who has NOT obtained the following credit weights by means of subjects and/or modules passed, may only continue his or her studies after permission is granted from the FAEAC.

A student who has not obtained the following credit weights through successfully completing subjects and/or modules, may continue with his or her studies only if the FAEAC grants him or her permission to do so, on his or her submitting full reasons for this rule to be relaxed due to extenuating circumstances. (Refer to Appendix: Faculty Academic Exclusion Appeals Guideline Document for details on extenuating circumstances.)

- An application with less than 30% of required credit accrued will not be considered for an appeal.

- At least 0.40 credit weight at the end of his or her first academic year or second academic semester (note that students registered for extended programmes have extended timeframes to acquire minimum credits. (Refer to Appendix: Guideline for Foundation Credits.))

- At least 1.00 credit weight at the end of his or her second academic year or fourth academic semester.

- At least 1.50 credit weights at the end of his or her third academic year or sixth academic semester.
• At least 2,00 credit weights at the end of his or her fourth academic year or eighth academic semester, which should include, at the very least, all the year or semester subjects that are required for the first year.

• At least 2,50 credit weights at the end of his or her fifth academic year or tenth academic semester.

• At least 3,00 credit weights at the end of his or her sixth academic year or twelfth academic semester.

• At least 4,00 credit weights at the end of his or her eighth academic year or sixteenth academic semester. (Only applicable to four-year Baccalaureus Technologiae degrees.)

• At least 0,50 credit weight at the end of his or her first academic year or second academic semester. (Only applicable to one-year Baccalaureus Technologiae degrees.)

• At least 1,00 credit weight at the end of his or her second academic year or fourth academic semester. (Only applicable to one-year Baccalaureus Technologiae degrees.)

Please note:

• Particular requirements on prerequisite subjects for promotion to a next academic level as published in the Prospectus are applied.

• The above restrictions shall also apply to students who change from one programme to another.

• Evening-class, block, or distant education students and students who took fewer than the required number of subjects, and who submit valid reasons, may apply for a proportionally weighted admission.

3.1.10 A single exclusion approach, with standard operating procedures and guidelines, shall be applied throughout the institution by all faculties and learning sites of TUT.

3.1.11 All stipulations in Chapter 3 of the Student Rules and Regulations for the appeal rules refer.

4. RELATED POLICIES

• Policy on Class Attendance
5. PROCEDURES

5.1 Procedure within Student Administration after student failed to achieve enough credits to be above the Academic Exclusion Threshold.

<table>
<thead>
<tr>
<th>REGISTRAR</th>
<th>PROCEDURE: ACADEMIC EXCLUSION OF STUDENTS</th>
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<tbody>
<tr>
<td>PURPOSE OF PROCEDURE</td>
<td>To provide a procedure to regulate the academic exclusion and conditional reregistration admission of students in terms of the exclusion clause.</td>
</tr>
<tr>
<td>SCOPE OF PROCEDURE</td>
<td>The procedure applies to the process from where students who did not perform satisfactorily are identified, excluded and successful appeal applicants are conditionally readmitted.</td>
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Abbreviations:
AR    Assistant Registrar: Student Administration
SSA   Student Services Administrator
ITS   Integrated Tertiary Software
FAEAC Faculty Academic Exclusion Appeals Committee
HoD   Head of Academic Department
Dean  Executive Dean of the Faculty
AQS   Academic Qualification System
<table>
<thead>
<tr>
<th>Input</th>
<th>Flow Diagram</th>
<th>Output</th>
<th>Docs</th>
<th>Who</th>
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<tbody>
<tr>
<td>AQS enters exclusion rules/criteria into ITS.</td>
<td>5.1 Students are identified electronically.</td>
<td>ITS report of excluded students</td>
<td>ITS report of excluded students</td>
<td>Student Services Administrator (SSA)</td>
</tr>
<tr>
<td>Final exam results</td>
<td>5.2 Report checked for the accuracy</td>
<td>Correctly identified student</td>
<td>Correctly identified student</td>
<td>SSA</td>
</tr>
<tr>
<td>Report of excluded students</td>
<td>5.3 Results of students who are electronically identified as exclusion candidates are endorsed with: “Excluded Letter Follows”.</td>
<td>To inform students</td>
<td>Individual results &amp; Exclusion Letter</td>
<td>Senior Student Administrator</td>
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<tr>
<td>Academic Exclusion printout &amp; Individual Student Academic Record</td>
<td>5.4 Academic records are submitted to Heads of Department, who will reconsider borderline cases.</td>
<td>Recommendations from HoDs</td>
<td>Academic Record with HoD recommendation</td>
<td>Senior Student Administrator/ HoD</td>
</tr>
<tr>
<td>Academic Records from Student Administration</td>
<td>5.5 The exclusions are activated on the students' academic records.</td>
<td>Exclusion block on student record</td>
<td>Final exclusion list</td>
<td>Senior Student Administrator</td>
</tr>
<tr>
<td>Recommendation from HoD</td>
<td>5.6 Students are sent letters of exclusion.</td>
<td>Exclusion Letter</td>
<td></td>
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<tr>
<td>Final Exclusion List</td>
<td>5.7 Students who are excluded are not permitted to register for the same programme</td>
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<td></td>
<td>5.8 Student may submit written appeal to the Head of Department</td>
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The flow diagram illustrates the process of academic exclusion in detail, starting with inputs such as exclusion rules, final exam results, and reports of excluded students. The process involves identifying students electronically, checking for accuracy, endorsing results with exclusion notices, and ultimately activating exclusions on academic records, informing students, and allowing appeals.
| Student receives exclusion letter with appeal forms | against the exclusion furnishing full reasons for the appeal before a specified date as published in the exclusion letter and the core calendar. | Departmental Academic Exclusion Appeals Committee | Departmental Academic Exclusion Appeals Committee/
FAEAC |
| --- | --- | --- | --- |
| Appeal forms | 5.9 The Head of Department submits all the applications (per prescribed template) for readmission to the Faculty Academic Exclusion Appeals Committee who considers the appeals. | Readmission of students or confirmation of exclusion | Committee Secretary/
Dean/
Asst Registrar: SA /
 |
| Agenda for Appeals Committee/ Appeal forms/ Supporting documents from student/ Academic records | 5.10 The Faculty Academic Exclusion Appeals Committee (as per prescribed membership) considers the appeals for re-admittance. | Readmission of students - list | Student Administration |
| Minutes (template) | 5.11 The Committee Secretary submits a final list, signed by the Chairperson of the Committee, of all students re-admitted to the Assistant Registrar: Student Administration, not later than seven days after the closing date for academic exclusion appeals. Conditions for re-admittance should be stated. | Readmission list | Executive Dean/
HoD/
Senior Student Administrator/
SRC/
Student/ Faculty Secretary. |
<p>| ITS Exclusion Programme | 5.12 The list is also posted on the official University Notice Boards. | | |
| Re-appeal request from the student | 5.13 Students that feel that they were unfairly treated by the Appeals Committee may re-appeal to the Executive Dean, whose decision will be final. | Final decision of the Executive Dean | |
| | | All original and new relevant supporting documentation | |</p>
<table>
<thead>
<tr>
<th>Application Form</th>
<th>5.14 Students who are excluded may apply for readmission after a period of two years.</th>
<th>HoD recommendation</th>
<th>Supporting documents from student/TUT acad. records</th>
<th>HoD/Student Administration</th>
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UNDERGRADUATE STUDIES