COULD INDUSTRIAL ENGINEERING TECHNIQUES IMPROVE RETENTION OF ENGINEERING STUDENTS IN HIGHER EDUCATION?

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ABSTRACT

By increasing the retention of engineering students at training institutions in South Africa it may be possible to increase the number of engineers in the country. Because of the international demand for engineers, emphasis is placed on engineering in the "list of occupations in high demand" in the Government Gazette in Nov 2014. South African Universities are constrained in terms of funds, infrastructure and teaching staff. The university's resources such as fees are optimised when more students are retained in a course. Many factors affect retention and there are many industrial engineering techniques that could be applied. One of the industrial engineering techniques that has been applied to retention is six sigma. The use of six sigma in academia and the challenges encountered have been documented. Challenges identified in a case study were the definition of the product and customer, measuring performance as well as addressing factors that cannot be controlled. This study used six sigma to improve retention of first year students. Retention was improved and the cost benefit calculated. The purpose of this paper is to look at industrial engineering techniques such as systems engineering, operations research, 20 keys to workplace improvement and value engineering to name a few, and how these techniques could theoretically be applied to improve engineering student retention.

1. INTRODUCTION

Engineering in general and industrial engineering specifically is a scarce skill as indicated on the South African scarce skills list **[1]**. It is potentially possible to increase the number of engineers by increasing the retention of engineering students in higher education. Retention of engineering students is not only a South African concern but also an international concern. In South Africa specifically access to tertiary education is a scarce resource. To optimise this scarce resource it is important to retain the students that enter the university and who have the potential to graduate.

The definition of industrial engineering according to the SAIIE website is: "Modern Industrial Engineering is concerned with the integration of resources and processes into cohesive strategies, structures and systems for the effective and efficient production of quality goods and services." **[2]** Industrial engineering is therefore about making things better, cheaper and faster. Therefore it should be possible to apply industrial engineering techniques to improve retention of engineering students

The objective of this study was:

i. To explore the reported use of industrial engineering techniques to improve engineering student retention

ii. To theorise as to how different industrial engineering techniques can be used to improve retention

2. RETENTION OF ENGINEERING STUDENTS

Retention of students is a concern for most tertiary education institutions. There are three main themes identified in the literature related to retention research **[3]**. They are firstly the internal and external

characteristics of students, secondly the conceptual and predictive retention models and thirdly the interventions to improve retention.

Internal characteristics include academic preparation, mathematics and science ability, self-efficacy, self-confidence, locus of control and different learning styles to name some. External characteristics include community, demographics and the university.

There are many different conceptual and predictive models. Conceptual models of which Tinto's model **[4]**, shown in Figure 1, is cited most often, help to better understand the retention problem.

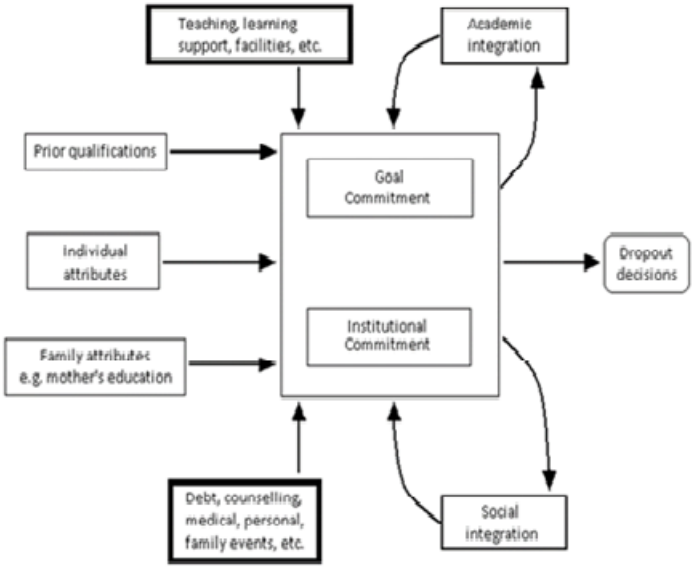

Fig. 1. Conceptual model by Tinto as adapted by Draper [5]

Predictive models use statistical methods to predict which students will be retained and which students are at risk of not being retained within a cohort for different parameter values. Some of the statistically motivated methods used in predictive models are neural networks, logistic regression and discriminant analysis **[6]**.

Interventions that have been suggested to improve retention are:

1) development of the faculty **[7]**;

2) support programs, here students are assisted with development of personal characteristics required for improving retention such as self-confidence and motivation and some programs focus on learning skills. **[8]**;

3) remedial or developmental course work such as improving academic preparation before the start of course work;

4) learning communities put in place to create opportunities for students to interact and learn together **[9]**, and

5) tailored intervention programmes **[10]**.

Retention is defined in many different ways. For the purpose of this article retention is defined as student retained in the faculty in which they initially registered, here specifically the engineering faculty i.e. the student starts and finishes their qualification in the engineering faculty. Measurement of actual total retention is fraught with complexity.

A great deal of research has been done on the retention of engineering students and yet little has been reported that indicates a significant improvement in retention. Further inquiry is therefore justified.

INDUSTRIAL ENGINEERING TECHNIQUES USED IN HIGHER EDUCATION

Several industrial engineering techniques have been applied to engineering education and specifically to the issue of retention. Perhaps the most common technique applied is Six Sigma. Six Sigma is a quality program

that is focused on continuously reducing defects and removing variation from a production line or process **[11]**. The aim is to have less than 3.4 defects per million items assessed. Six Sigma is focused on data, measurement and precision **[12]**. Customer focus is critical to the success of any six sigma program **[13]**. Six Sigma is completed in five phases design, measure, analyse, improve and control (DMAIC). Several tools and techniques can be used to achieve improvement such as: Cause and effect analysis, failure modes effect analysis, statistical analysis, project charter, brainstorming, process maps, Pareto analysis , check sheets, histograms, process control charts and the voice of the customer **[14]**

Several articles have been written concerning the improvement of retention by using Six Sigma. Hargrove and Burge **[15]** first step was to identify the attrition factors, based on surveys and applying Quality Function Deployment (QFD), and to determine which factors were responsible for most attrition. They found that three of the ten dominating factors contributed to 45% of student loss. The Six Sigma capability index was calculated to be three. The three factors identified were financial aid, faculty development and improving quality of instruction. They also created a student success model with the dominant attributes of an engineering graduate. This study was conducted over a six year period and therefore the process cycle time was twelve semesters with each semester seen as an opportunity for a defect **[15]**. It is suggested that the use of Six Sigma in academia is not about achieving a virtually defect free environment but rather about using data and statistical analysis to identify the causes of errors and removing those errors **[16]**.

At the West Virginia University, Jaraiedi, Iskander and Agrawal determined characteristics that predicted retention and they deemed defects or failures as students who could not return to engineering **[16]**. DMAIC was applied, in this case improvements could only be suggested and not implemented. They used the Supplier-Inputs-Process-Outputs-Customers (SIPOC) process to identify all the factors that affect retention rates.

In a study by Chow and Downing student focus groups and surveys were used to identify factors that affect retention. With hypotheses testing and linear regression the factors with the greatest impact were identified. In this study more focus was placed on the retention strategies employed **[17]**. Over a five year period they were able to achieve a 2.5% improvement in retention. Six Sigma was proven to be helpful in organising projects and communicating results. Challenges encountered in implementing Six Sigma in academia were defining key customers as well as the relevant process metrics **[17]**.

The lost revenue of students dropping out is significant. Midwestern University estimated that a dropout rate of 20% for a student group of 4000 student exceeded $ 25 million in foregone revenues **[14]**. Determining the root causes of failure is an important step in six sigma. Every root cause needs to be examined to determine whether it is being caused by other more important causes. The goal should always be a significant reduction in defects **[14]**.

Six Sigma has also been used in curriculum development in Malaysia with the aim to produce engineers who are globally minded, can easily adapt to new conditions and are innovative **[18]**.

Another approach has been to combine Six Sigma with Lean. Lean philosophy is about reducing waste and adding value to the customer **[19]**. There are seven wastes that Lean focuses on, they are: over production, over processing, defects, inventory, transportation, waiting and unnecessary motion. The first step is to identify which processes add value. A value stream map is created to determine this. Lean and Six Sigma are suited to be used in conjunction with each other **[20]**. One of the aspects that could benefit from Lean Six Sigma is the curriculum delivery. Universities and training institutions recognise external customers' (those employing the graduates), needs, however, the main customer should always be the students as universities are about preparing students for lucrative employment **[20]**. The universities' relationship with students is in some regards seen as more complex than the relationship with a customer yet the universities want to attract and retain them. Lean Six Sigma could be applied to measure the success of employment placement and the extent of engagement with external customers. Lean Six Sigma could also be used to determine faculty allocation, where faculty should be viewed as a resource to be applied to the benefit of the customers and the career path of the faculty. Lean Six Sigma could also potentially improve the revenue cycle, specifically the timing of receipt of tuition and fees. Reducing expenses is another area Lean Six Sigma could be applied to. There are opportunities to apply Lean Six Sigma in the process of admissions, enrolment as well as marketing **[20]**. All these factors impact student retention from curriculum development to marketing, and therefore improvements of these processes could potentially improve retention.

Data mining has been used to predict student attrition **[21]**. Data mining is the process of finding patterns in large data sets. Data mining has also been used to explore student characteristics associated with retention that leads to graduation in higher education **[22]**. This study found that it was possible to predict retention leading to graduation as early as at the end of the first semester. Decision tree and logistic regression models identified

first semester Grade Point Average (GPA), earned credits at the end of the first semester, full or part time status of the students as well as high school GPA as the most important factors.

Machine learning, a process of automated learning from existing data by using models and algorithms. Machine learning was used at Oklahoma State University to predict and understand the institution specific nature of the attrition problem by using five years historical data **[23]**.

An industrial engineering approach has been used to develop an industrial engineering curriculum **[24]**. Here the voice of the customer, Quality Function Deployment (QFD), process mapping and design, process optimisation, lean design, product customisation an operations strategies were used to develop the curriculum. This lead to a competitive curriculum and processes aligned with the specific university strategy. Operations research was used to design the curriculum at the University of Connecticut **[25]**. As the curriculum is central to what students are taught and this directly impacts student retention, it is important to carefully consider what is taught, what is not taught and at what level to teach the content. This study used dynamic programming to optimise their curriculum. Mathematical solution systems are beneficial for rational decision making in complex situations. The mathematical goal is usually to optimise some function. The problem here is to identify the function that will guarantee improved retention when optimised.

Statistical Process Control (SPC) has been used to improve classroom practice **[26]**. This approach was used in a quality improvement course with the goal of continuous improvement of lectures. Students generated the data by evaluating the lecture after the presentation was completed and then students analysed this data using SPC. The standardised lecturer assessment form was used as a starting point, with input from the students the form was consolidated and a new assessment form developed. The new form had a response scale from 1 – 10, where 1 indicated strong disapproval and 10 indicated strong approval. The assessment was divided into three general categories: the professor, the material and the course. This form was then given to students at the end of each lecture starting at the second week of lectures and ending midterm. To ensure students remained anonymous students chose fictitious names and used those the entire semester. The assessment data provided daily feedback to the lecturer and demonstrates SPC concepts to students. Control charts were used to determine whether the process was "in control". Low points were investigated using other SPC techniques, such as cause and effect diagrams, to determine the root cause. High ratings were also investigated to determine what the lecturer did well. The lecturer could then use the information to monitor effectiveness of lectures and make adjustments as required **[26]**.

Total Quality Management (TQM) has been used to improve quality of education. Sakthivel and Raju developed an instrument to measure the quality level of the education offered **[27]**. They identified seven critical factors of education service quality they are: 1) Commitment of top management and leadership, 2) Customer focus, 3) Course delivery, 4) Communication, 5) Campus facilities, 6) Congenial learning environment, 7) Continuous assessment and improvement. They also identified two performance variables: 1) customer value and 2) customer satisfaction. One of the outcomes of improved quality would potentially be improved retention.

In India, technical educational institutions, used Tagushi's quality loss function and analytic network process (ANP) to develop a conceptual model for campus placement **[28]**. By selectively matching student's skills through ANP the total loss in terms of opportunity costs can be minimised.

The state of Kentucky embarked on a state-wide educational reform program. Welsh, Petrosko and Taylor found that the educational reform effort had very little impact on the retention of undergraduate students **[29]**. They suggested high schools and colleges may be able to improve retention by developing a student information system based on the concept of "supply chain management". Supply chain management is about the management from supplier to customer. Interaction with suppliers is important to optimise final products, organisations need to understand how they impact each other and what is required for success. Universities need to learn more about their suppliers namely high schools. Supply chain management requires the sharing and collaboration of appropriate data. Improving the relationship between high schools and universities provide opportunities to improve student retention. **[29]**.

3. THE APPLICATION OF INDUSTRIAL ENGINEERING TECHNIQUES TO IMPROVE RETENTION THEORETICALLY.

Key aspects to focus on have been identified at the University of Johannesburg in the strategy for teaching and learning **[30]**. The aspects are: a) Recruitment, b) Curriculum c) Assessment practices d) Pedagogy (method of teaching) e) Costs f) Interventions g) Facilities, lecture venues and study areas h) Failure rates i) Leaving the course j) Success rate in industry k) Staff qualifications and l) Learning needs of first generation students.

As seen in the section above many different industrial engineering techniques have been applied to many different aspects of teaching and learning specifically with the aim to improve retention. More industrial engineering techniques could theoretically be applied to improve various aspects of teaching and learning.

Systems engineering focuses on using techniques and modelling to better understand and improve systems as they grow more complex. These concepts: systems, systems thinking and systems approach are used across many different disciplines **[31]**. Systems thinking requires an understanding of the whole system as solving separate

parts of the problem may not solve the whole problem **[32]**. A system level model is created, which becomes the conceptual model of the system. As many conceptual models of retention exists it may be possible to apply systems engineering to improve retention by using already existing conceptual models. Business process re-engineering is often seen as a subset of systems engineering **[31]**.

Value engineering is a systematic approach to improve the value of a product or process by improving the value to the customer by analysing the relationship between the function and the cost. Value engineering is particularly useful at the design stage of the process **[33]**. However it can also be applied to other stages of any process. Attention should be given to key value adding activities. This approach could be used in improving retention by isolating the value adding activities and focussing on their improvement. Value adding activities could be interventions to improve retention, teaching and learning aspects and identifying students at risk for attrition early. As retention of students is a multi-faceted problem it is difficult to even understand what the various value adding activities are. The philosophical question is how to identify with certainty the correct activities that would form the basis of the intervention proposed.

Operations research uses advanced analytical methods to make better decisions. Assignment models could be used to assign staff to subjects. Decision theory and decision trees could be used to optimise both the University as well as students' resources.

Twenty Keys to workplace improvement is another holistic approach to improving involvement, productivity and quality of a system **[34]**. There are five levels for each of the 20 keys, the status for each of the keys are determined and then action is taken to move the key from its current level to the next level.

The Theory of Constraints is a methodology of finding the factor that most limits, or constrains, the achievement of the goal. In manufacturing these constraints are called bottlenecks. Then to focus attention on optimising the constraint **[35]**. This could also be applied to the retention problem by identifying the major constraints in the curriculum as well as in the characteristics of students that leads to lowered retention and then working on reducing the impact of the identified constraints.

Lean philosophy could also be applied more comprehensively to the retention problem. By identifying the value and removing all waste from the value stream retention could in theory be improved.

4. CONCLUSION AND RECOMMENDATION

The problem of retention of engineering students is a complex problem with many contributing factors and a university's system of teaching and learning is an equally complex system. It can be seen that different industrial engineering techniques were applied to different components of the problem with some success. It may however be that significant improvement have not been realised as the problem and system as a whole has not been addressed. In all likelihood this failure in the past was due to the complexity and scope of the retention problem.

Industrial engineering techniques most often used in improving retention are Quality Engineering techniques such as TQM and Six Sigma.

The researchers believe that many of the industrial engineering techniques could be beneficial to solving this problem and many of the systematic problem solving approaches could be applied. These different tools should be compared and a selection should be made on what suits the environment which needs to be improved as well as the culture of the organisation **[36]**. To successfully implement any improvement methodology the support of all role-players will be required. This may be difficult to achieve in a large organisation such as a university.

The most relevant techniques are probably Six Sigma, Lean, Systems Engineering, Data Mining and Twenty Keys to workplace improvement. All of these techniques are able to address complex problems holistically.

The main contribution of this paper is to identify industrial engineering technique that have been used and could potentially be used to improve retention of engineering students. It is clear that industrial engineering can improve retention of engineering students. By improving retention, resources are optimised and it may potentially lead to increasing the number of engineering graduates finishing their studies each year in South Africa. South Africa will benefit from this as engineers and specifically industrial engineers have an important role to play in the economic growth and competitiveness of the country.

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