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"The Use of Six Sigma to Improve The Quality of Engineering Education"

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Introduction

One of the most powerful business strategies for improving quality is Six Sigma, a breakthrough methodology [25]. If implemented properly this methodology provides maximum value to an organization [34]. The Six Sigma approach is to improve the quality of a process and profitability of the business by reducing the number of defects through the application of statistical methods [15] [16]. The methodology is designed to capture and use many of the tools used in quality control, process control, and continuous improvement. It applies to far more than just industrial processes - it applies to product design, engineering, any commercial process, and customer service [28]. Service-based processes have even more opportunities for improvement than manufacturing operations [3] [10]. This is especially true for academia. A college, like a business organization, must compete for its customers. Many college administrators have not been sensitive to outside customers such as parents, employers, graduate schools, and society, and the impact that they may have on the quality in education. These matters are considered in the model.

The Six Sigma Way

Six Sigma is in many ways a powerful regeneration of quality ideas and methods. Except that the Six Sigma way is revealing a potential for success that goes beyond the levels of improvement achieved through the many TQM[1] efforts. The objective of *Six Sigma performance* is to reduce or narrow variation to such degree that standard deviation of variation can be squeezed within the limits defined by the customer's specification. For many products, services, and processes that means a potential for enormous improvement. The statistics associated with Six Sigma is relatively simple. To define Six Sigma statistically, two concepts need to be defined: specification limits and normal distribution.

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[1] TQM – Total Quality Management

Specification limits are the tolerance or performance ranges that customers demand of the products or processes they are purchasing. Because variability is so ubiquitous in the real world, the specification limits should be set in such way that permits some degree of imprecision in the work done.

Sigma levels of performance are expressed often in Defects per Million Opportunities (DPMO) For "typical" shift of a process mean from a specification for every 100 product units, 93.32 of them will have desired characteristics that fall within $\mp 3\ \sigma$. This corresponds to approximately 66,800 defective units per million of the products for $\mp 3\ \sigma$. For the $\mp 6\ \sigma$ process performance there is only 3.4 DPMO. However, improvement from a three to a four sigma quality level is not the same as an improvement from a five to a six sigma quality level. A shift in sigma quality level from five to Six Sigma is a much more difficult improvement effort than a shift in sigma quality level from three to four sigma.

The DMAIC[2] Assessment Model

The real value of Six Sigma is orchestrating process improvement and reengineering bottom line benefits through a wise implementation of statistical techniques [15][16]. A Six Sigma program needs to be orchestrated toward achieving Smarter Six Sigma Solution[3], which usually refers to a five-phase improvement cycle that has become increasingly common in Six Sigma organizations: Define – Measure – Analyze – Improve – Control, or DMAIC. The question is how to adopt this approach to meet unique challenges in the service sector, since that is the focus of this paper. The paper describes a generic assessment model for a college of engineering as an annual cycle that consists of a systematic assessment of every course in the program, followed by an assessment of the program, and the college as a whole using Six Sigma methodology.

However, it is important to note that application of Six Sigma in academia does not mean achievement of six sigma level of quality of virtually defect free operation. It is rather a methodology of using extremely rigorous data-gathering and statistical analysis to identify sources of errors and ways of eliminating them. The DMAIC continuous improvement cycle described below is adapted to the specific environment of an engineering program. The results of assessment for each DMAIC cycle of an engineering program are documented in order to insure continuous improvement.

The Industrial and Manufacturing Engineering Program (IME) in the College of Engineering at the University of Cincinnati will be used as a case example for a preliminary test of the generic model.

In Educational Settings the Educational Programs Are Assessed For Quality

Six Sigma is a fluid methodology that works at any level of the organization if long-term improvements are to be made. Almost every organization can be broken down into three basic

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[2] DMAIC – Define, Measure, Analyze, Improve, and Control

[3] Smarter Six Sigma Solution, also known as S^4, is a term used by Breyfofle III [15].

levels. The higher level is corporate level where executives use Six Sigma to ensure the organization's long-term capability. The mid and lower level are operation and process level respectively where managers use Six Sigma to reduce variation and meet operational goals (college objectives and outcomes) leading to improve customer satisfaction.

However, the key to assessing quality in academia is to clearly define the process that occurs in the educational settings, and to identify those processes important to customer satisfaction. A vital process to customer satisfaction in academia is *an educational program*. Educational programs rather, than institutions, departments, or degrees are assessed for quality.

Also, the assessment process must demonstrate that the outcomes important to the mission of the institution and the objectives of the program are being measured. A fundamental goal in a total quality setting is continuous quality improvement. In order to continuously improve the quality of service it is necessary to continually improve the system. DMAIC strategic plan should be developed with respect to each program's long-term goals. Indeed, adding value to the quality in education as a long-term goal will provide programs, and a college as a whole, with sustainable competitive advantage in the marketplace.

Core Processes and Key Customers

Although it does not belong to any of the five phases in Six Sigma methodology, the "identification" of key processes and key customers of the organization is in fact the starting point of the model[4]. Essential processes behind an engineering program strategic plan are broken down into two parts – coursework and professional practice with an actual employer. Also, the driving forces of the program are: the primary customer, the student, and the program external customers – parents, employers, graduate schools, community and society, and professional societies.

"Define" Phase

In this phase it is important to understand what customers really want – and how their needs, requirements, and attitudes change over time [[28]]. Making it a continuous effort may be critical to business success.

Defining Customer Requirements and Program Objectives

It is the responsibility of the program and the assessment team to continuously monitor and apply the customers' requirements. A program should be driven by establishing goals, by defining measurable program objectives, by establishing an effective process, and by determining program outcomes that result from achieving program objectives.

The first step before a program's assessor starts with the assessment process is to define program objectives and seek outcomes. The objectives of the program would broadly reflect the needs of

[4] Some authors in the area of Six Sigma strategy even recognize it as the actual first phase of Six Sigma methodology.

the students and the community as well. As an example, the Industrial and Manufacturing Engineering[5] program objectives are listed below.

1. To provide students with knowledge of mathematical, physical and social sciences; economic, operational and engineering analyses; and the principles and techniques of engineering design.

2. To provide students with a solid background in principles and methods of basic manufacturing processes, advanced manufacturing systems, and the applications of control theory and digital system techniques in manufacturing (processes).

3. To prepare students to design, install, and improve complex systems and processes, which integrate people, materials, and equipment, and thereby place unique demands for breadth of preparation upon industrial engineers.

4. To emphasize the principles of probability, statistical inference, quality control and reliability, operations research and their applications in engineering, and the utilization of human resources, productivity improvement, and interdisciplinary topics such as biomechanics, engineering economy and numerical methods.

5. To prepare students for professional practice and further study in the area of industrial engineering emphasizing students' creativity, innovation, teamwork, leadership roles in industry by propagating these ideas into project topics.

The evaluation of how well the objectives are being met depends on the program outcome assessment. Since most of the engineering colleges are seeking ABET[6] accreditation and are therefore obligated to satisfy eleven ABET educational outcomes' requirements, it is only appropriate to incorporate ABET outcomes into this model as the program outcomes. The list of program outcomes could be, however, expanded with respect to the program educational goals. The College of Engineering, University of Cincinnati, will, demonstrate that its graduates meet eleven ABET outcomes:

a. Ability to apply knowledge of mathematics, science, and engineering
b. Ability to design and conduct experiments, as well as to analyze and interpret data
c. Ability to design a system, component, or process to meet desired needs
d. Ability to function on multi-disciplinary teams
e. Ability to identify, formulate, and solve engineering problems
f. Understanding of professional and ethical responsibility
g. Ability to communicate effectively
h. Broad education necessary to understand the impact of engineering solutions in a global and societal context
i. Recognition of the need for and the ability to engage in life-long learning
j. Knowledge of contemporary issues
k. Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

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[5] Industrial Engineering Program at the University of Cincinnati, College of Engineering
[6] ABET - Accreditation Board for Engineering and Technology

The correlation between IME program's educational objectives and the program outcomes is presented in Table 1. Each educational objective meets several program outcomes. The correlation is indicated by "✓" marker.

Table 1. Programs Educational Objectives and the Program Outcomes Correlation

	IME Programs Educational Objective	ABET Outcome										
		a	b	c	d	e	f	g	h	i	j	k
1	To provide students with knowledge of mathematical, physical, and social sciences; economic, operational and engineering analyses; and the principles and techniques of engineering design	✓				✓			✓	✓		
2	To provide students with a solid background in principles and methods of basic manufacturing processes, advanced manufacturing systems, and the applications of control theory and digital system techniques in manufacturing (processes).	✓	✓			✓			✓			✓
3	To prepare students to design, install, and improve complex systems and processes, which integrate people, materials, and equipment, and thereby place unique demands for breadth of preparation upon industrial engineers.	✓	✓		✓	✓		✓	✓	✓	✓	✓
4	To emphasize the principles of probability, statistical inference, quality control and reliability, operations research and their applications in engineering, and the utilization of human resources, productivity improvement, and interdisciplinary topics such as biomechanics, engineering economy and numerical methods	✓	✓			✓			✓			✓
5	To prepare students for professional practice and further study in the area of industrial engineering emphasizing students' creativity, innovation, teamwork, leadership roles in the industry by propagating these ideas into project topics.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Realizing the relationship between program's educational objectives and the program outcomes is important to achieve the final model objective - facilitate continuous improvement. For the same reason students' coursework should be identified through the program objectives. Not every course needs to satisfy all program objectives. However, the objectives should be executed through a program curriculum. The relationship between IME Program curriculum that meets relevant IME program objectives is shown in Table 2.

Table 2. IME Program Courses That Meet Relevant IME Program Objectives

No	COURSE	Appropriate IME Program Educational Objectives
	Year III	
1	MATH276 Matrix Methods	1
2	ENFD371 Elec. Crct. Anal.	1 2 3 4
3	ENFD383 Basic Fluid Mech.	1 2 5
4	INDS354 Manuf. Process. I	1 2 3 5
5	MINE340 Eng. Stat. Meth.	1 4
6	ENFD385 Basic Heat Trans.	1 3 4
7	INDS322 Numerical Methods	1 3
8	INDS341 Eng.Stat.Meth. II	1 4
9	INDS355 Manuf.Process. II	1 2 3 4 5
	Year IV	
10	INDS438 Ergonomics	2 3 4 5
11	INDS440 Work Measurement	1 2 3 4 5
12	INDS453 Operations Rsch. I	1 2 4
13	INDS475 Manufac. Controls	1 2 3 4 5
14	INDS454 Operations Rsch. II	1 2 3 4 5
15	INDS470 Lab. for IE	1 2
16	MINE451 Engr. Economy	1 2 3 4 5
	Year V	
17	INDS552 Facilities Design	1 2 3 4 5
18	INDS511 Quality Control	1 2 3 4 5
19	INDS555 Simulation	1 2 3 4 5
20	INDS556 Prod. Plan & Con.	1 2 3 4 5
21	MINE586 Clinic I	1 2 3 4 5
22	MINE586 Clinic II	1 2 3 4 5
23	MINE587 Clinic III	1 2 3 4 5
24	MIE Elec. 1	1 2 3 4 5
25	MIE Elec. 2	1 2 3 4 5
26	MIE Elec. 3	1 2 3 4 5
27	MIE Elec. 4	1 2 3 4 5

In order to capture most of the program educational outcomes the portfolio material is collected considering eight different educational goals:

- *Portfolio Aspect I:* Skills in Calculus, Physics, Chemistry and Electronics.
- *Portfolio Aspect II*: Writing and Communication Skills
- *Portfolio Aspect III*: Engineering Design Skills
- *Portfolio Aspect IV*: Information Systems and Computer Skills
- *Portfolio Aspect V*: Engineering Measurement Skills
- *Portfolio Aspect VI:* Management Skills
- *Portfolio Aspect VII:* Economics Skills
- *Portfolio Aspect VIII*: Skills in Engineering Science

Each course in an engineering program could be "inspected" from the eight aspects listed above and the evidence collected and stored for future analysis. The correlation that has been developed between IME courses and the eight portfolio aspects is sown in Table 3.

Table 3. IME Program Course That Meet Relevant Portfolio Aspects

No	COURSE	Appropriate Portfolio Aspects
	Year III	
1	MATH276 Matrix Methods	I
2	ENFD371 Elec. Crct. Anal.	I III IV V VIII
3	ENFD383 Basic Fluid Mech.	I III IV V VIII
4	INDS354 Manuf. Process. I	I III IV V VIII
5	MINE340 Eng. Stat. Meth.	1 VII VIII
6	ENFD385 Basic Heat Trans.	I III IV V VIII
7	INDS322 Numerical Methods	I III IV V VIII
8	INDS341 Eng.Stat.Meth. II	I III IV V VIII
9	INDS355 Manuf.Process. II	I II III IV V VII VIII
	Year IV	
10	INDS438 Ergonomics	II III IV V VII VIII
11	INDS440 Work Measurement	I II III IV V VI VII VIII
12	INDS453 Operations Rsch. I	I II V VIII
13	INDS475 Manufac. Controls	I II III IV V VIII
14	INDS454 Operations Rsch. II	I II IV V VIII
15	INDS470 Lab. for IE	I II V
16	MINE451 Engr. Economy	I II IV V VI VII VIII
	Year V	
17	INDS452 Facilities Design	I II III IV V VII VIII
18	INDS411 Quality Control	I IV VI VII VIII
19	INDS555 Simulation	I II III IV VI VII VIII
20	INDS556 Prod. Plan & Con.	I II III IV V VI VII VIII
21	MINE586 Clinic I	I II III IV V VI VII VIII
22	MINE586 Clinic II	I II III IV V VI VII VIII
23	MINE587 Clinic III	I II III IV V VI VII VIII
24	MIE Elec. 1	I II III IV V VI VII VIII
25	MIE Elec. 2	I II III IV V VI VII VIII
26	MIE Elec. 3	I II III IV V VI VII VIII
27	MIE Elec. 4	I II III IV V VI VII VIII

"Measurement" Phase

This phase is about gathering enough data to compare business core processes. In any Six Sigma initiative other than training, measurement is the biggest task for many business systems. In many cases it can take a lot of time to collect enough evidence to perform valid analysis. The measurement phase must answer two fundamental questions: what to measure, and how to measure.

Measuring program performance also requires a performance tracking system that is capable of "cutting" through data in many different ways. That is why it is important to develop such measuring techniques so that assessors are able to hierarchically pool data to the appropriate business levels.

Measuring Current Performance

Multiple assessment tools must be developed and implemented to validate the achievement of program outcomes. It is essential for a quality assessment to check whether the students have acquired content knowledge, whether they can construct an argument, operate machinery correctly, or be decision makers in a major project. To collect this kind of information, colleges use different assessment tools. One of the most popular and most effective is students' portfolio – the collections of multiple students' work samples compiled over time. On the other hand, it is more difficult, though not impossible, to assess students on such attributes as "achievement of self-awareness" and "independence." Different types of surveys are designed to cover areas of learning that might be difficult or costly to assess more directly. Also, surveys can provide a program with access to individuals who otherwise would be difficult to include in the assessment efforts (e.g. alumni, parents, employers), and get an insight to standards that a program needs to have, and information on important trends in business.

To make the assessment process as simple as possible, which is very important at the beginning, the first assessment cycle of a program is based on four types of the assessment tools: surveys, exit interviews, portfolio, and student co-op performance data. As the assessment progresses additional assessment tools should be considered. Detailed description of the assessment tools proposed in this model is presented in the paper entitled "Model for ABET 2000 using Six Sigma Methodology" [26].

Portfolios document individual as well as collective achievements of an entire group. In order to capture most of the program educational outcomes the portfolio material is collected considering eight different educational goals. The course work is broken down into different educational aspects, the eight portfolio aspects, which allow the educators to simultaneously monitor different skills that students should master as college graduates. The professor will assign different grades for student's writing skills, engineering design skills, IT skills, management skills, economics skills, and skills in engineering science. Students' achievements assessed this way highlight potential problems in education, and alter the outcomes of a program as well.

Most assessment experts agree that no single instrument is adequate and that the assessors need to use several assessment techniques simultaneously. Techniques like surveys, interviews, and third party reports provide assessors with valuable information. Each survey provides specific questions depending on the audience surveyed. Questions range from individual perceptions of the quality of specific courses and activities, to faculty evaluations, relationship with industry, to more general questions surveying the overall impact. Also, the surveys provide for comments and suggestions for improvement.

There are three different surveys developed to support the assessment process in the IME program: Co-op employer survey, Co-op student survey, and alumni survey. The IME program also conducts student exit interviews required by the College of Engineering. The questions are developed in such a way so that they directly correspond to the eleven program outcomes. The co-op employer survey is presented as an example. The questions are designed to match the program outcomes as well.

EMPLOYER SURVEY

(ASSESSMENT OF A STUDENT'S PROFESSIONAL PRACTICE)

Unsatisfactory *Poor* *Satisfactory* *Good* *Excellent*

1. Student's ability to apply knowledge of mathematics, science, and engineering is:
2. Student's communication skills (effective presentation, writes clearly and concisely, speaks effectively and clearly) is:
3. Student's ability to evaluate situations effectively is:
4. Student's ability to solve problems/make decisions is:
5. Student's professional attitude toward work assigned is:
6. Student's ability to demonstrate original and creative thinking is:
7. Student's ability to apply classroom learning to work situations is:
8. Student assumes responsibility and is accountable for actions.
9. Student shows initiative.
10. Student demonstrates a positive attitude toward change.
11. Student understands and contributes to the organizational goals.
12. Student functions well on multidisciplinary teams.
13. Student possesses honesty, integrity, and personal ethics.
14. Student uses technology, tools, instruments, and information.
15. Student understands complex systems and their interrelationships.
16. Student understands the technology of the discipline.
17. Student understands and works within the culture of the group.
18. Student respects diversity.
19. Student recognizes political and social implications of actions.

The relationship between the assessment tools, the surveys and portfolio aspects, and the IME program outcomes is specified in Table 3. In the table, for example, IME program outcome "a" – students' ability to apply knowledge of mathematics, science, and engineering, is assessed by: questions 5, 6, 19, of the student exit survey, question 5 of the alumni survey, question 1of the employer co-op survey, question 1 of the student co-op survey, and the first aspect of the portfolio. Each of the listed survey tools will control the final value of the program outcome "a" by a certain percentage. It is important to recognize at this point that a direct link is established between the students' course work and the student's professional practice, and program learning outcomes. The link is designed in such way so that collected data reflects the needs, expectations, and satisfaction or dissatisfaction levels of the students, alumni, and employers as well. Table 3 is an example of the mapping method.

Table3. Mapping of the Assessment Tools to IME Program Outcomes

IME Program Outcomes	Student Exit Survey	Alumni Survey	Employer Co-op Survey	Student Co-op Survey	Portfolio Aspects
a	5 6 19	5	1	1	I VIII
b	15 20	6	3 11	3	V
c	8	6	4 6 7	4 6	III VIII
d	9 17	12	9 12	8 9 14	IV VIII
e	7 12	10 14	7 15	12	III VIII
f	13	8 11	5 8 13	5 7 10	VI
g	10 11	12	2	2	II
h	25	7	16 17 19	12 13 16 18 19	VIII VI
i	21	9	9 10 17 19	8 15 16 18	
j	13	11	11 18 19	14 17 18	VI VII
k	14 16	14	7 10 14	11	IV V

Mechanism of the Model

Getting good customer input on a program's needs and requirements may be the most challenging aspect of the Six Sigma approach. The assessment of an engineering program is even a more challenging assignment. The amount of data that must be processed is substantial. In addition, the results of the data processing have to be available for analysis by the end of each academic year.

A robust database system is an effective, very fast, systematic, and relatively inexpensive way of collecting and processing a large amount of data. Also, the database system provides strategically grouped, filtered, and tabulated data in a form of fairly simple reports. There are several data sources as valid inputs for the performance measurement system (database): students' portfolio, co-op employer survey, co-op student surveys, student exit surveys, and alumni surveys. The data will be collected on-line. In this way the data inputs are fast, and the data is most accurate and most recent.

Collecting evidence and summarizing the results from the surveys and students' portfolio will be handled by a database tabular structure. This structure then translates itself into easy-to-read reports. The database reports will accurately exhibit a program performance according to the inputs and also calculate the satisfactory level for ABET requirements. Each of the assessment inputs contributes to the final estimate of the program outcomes in a certain percentage.

"Analysis" Phase

In this phase the assessors use measures to find out why things are happening in the process the way they do. They also want to find out which process is involved, what is wrong, and what and how big is the opportunity for improvement. The model responds to these questions through the database design, a key building block for organizational Six Sigma system [[28]].

Prioritize and Analyze

The primary purpose of the database is to extract information gathered by assessment tools for particular conditions like process improvement. The relationship between students and assessment tools data needs to be a strong one-to-one relationship so that improvement areas are easy to identify. Parallel to this inference the program is measuring the outcomes using the same data (see Table 6).

Some of the valuable information can be drawn from statistics on the data taken directly from the tables – an example would be two-year alumni annual surveys. Here are some of the requests that the database design should be suitable for:

1. Report on the course work for a particular student evaluated for all portfolio aspects. (Table 4)
2. Report on a particular student co-op performance. (Table 5)
3. Report on the ABET eleven outcomes of the IME program from the alumni survey aspect. (Table 6)
4. IME Program Outcomes Evaluation Final Report – Academic Year 2000. (Table 7)

Table 4. Report on the course work for a particular student evaluated for all portfolio aspects

Report 1. The Course Work of a Particular Evaluated Student

PF =Portfolio Aspect

SSNo	CourseNo	PF1	PF2	PF3	PF4	PF5	PF6	PF7	PF8
1111000									
	ENFD371	4		3	4	4			3
	ENFD383	4		4	5	4			4
	ENFD385	4		3	4	4			3
	INDS322	4		3	4	4			3
	INDS341	5				5	5	5	5
	INDS354	5		3	2	4			3
	INDS355	4	4	4	4	5		4	4
	INDS411	3			3		3	4	5
	INDS438		5	2	2	5		5	5
	INDS440	5	5	5	5	5	5	5	5
	INDS452	4	4	5	5	5		5	5
	INDS453	4	5			4			5
	INDS454	4	4		4	4			4
	INDS470	4	4			4			
	INDS475	4	4	4	4	4			4
	INDS512	3	3	3	3				3
	INDS520	4	4	4		4	4	4	5
	INDS555	4	4	4	4		4	4	4
	INDS556	4	5	5	5	5	5	5	5
	MINE340	5						5	5
	MINE451	5	5		5		5	5	5
	MINE585	4	4	5	4	4	4	4	5

Table 5. Report on a particular student co-op performance.

Report 4. Employer Evaluation of a Particular Student

EQ =Employer Survey

SSNo	*Education Year*	*Quarter*	*Year*	*Employer*	EQ1	EQ2	EQ3	EQ4	EQ5	EQ6	EQ7	EQ8	EQ9	EQ10	EQ11	EQ12	EQ13	EQ14	EQ15	EQ16	EQ17	EQ18	
1111000	Sophomore	*Spring*	1997	Company	4	2	3	4	3	3	4	3	4	3	2	2	3	4	4	4	3	5	5
	Pre junior	*Spring*	1998	Company	4	2	4	3	4	3	3	3	3	4	4	2	5	4	4	4	4	4	3
	Junior	*Spring*	1999	Company	3	3	4	3	4	4	4	4	4	5	3	3	3	4	4	5	4	5	5
Avg					*3.67*	*2.33*	*3.67*	*3.33*	*3.67*	*3.33*	*3.67*	*3.33*	*3.67*	*4*	*3*	*2.33*	*3.67*	*4*	*4*	*4.33*	*3.67*	*4.67*	*4.33*

Summary for 'EmployerSurvey.SSNo' = 1111000 (3 detail records)

Table 6. Report on ABET eleven outcomes of the IME program from the alumni survey aspect.

Report 5. Evaluation of IME Program Outcomes by Alumni - Generation of '95

Alumni from year:	**1995**
Program outcome (a):	**4.50**
outcome (b):	**4.10**
outcome (c):	**4.10**
outcome (d):	**4.20**
outcome (e):	**3.40**
outcome (f):	**4.15**
outcome (g):	**4.20**
outcome (h):	**3.60**
outcome (i):	**4.40**
outcome (j):	**3.90**
outcome (k):	**3.30**

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Table 7. IME Program Outcomes Evaluation Final Report – Academic Year 2000.

Report 6. ***IME Program Outcomes Evaluation***
Final Report – Academic Year 2000

Program outcome (a):	**3.60**
outcome (b):	**3.74**
outcome (c):	**3.05**
outcome (d):	**3.61**
outcome (e):	**3.92**
outcome (f):	**3.71**
outcome (g):	**3.45**
outcome (h):	**3.86**
outcome (i):	**3.71**
outcome (j):	**3.72**
outcome (k):	**3.83**

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Report 5 from Table 3 is one of the four final database reports designed for a program performance evaluation. Report 5 represents alumni evaluation for a particular academic year. The report is a simple list of program outcome values. The other three reports are the program outcome evaluations measured by the other independent sources: senior students, professors, and employers. Each of the reports makes a certain percentage contribution to the final value of the program outcomes. The Final Report (Report 6, Table 7) of the program evaluation is again straightforward information on how well an engineering program is doing according to the students' work and the external customers. This simplified summary is however, the result of a large, complex, and diverse data collection. As much as 63,000 data points are processed, summarized, and translated into dozens of reports for further analysis each year.

This final report (Report 6) is the starting point in the analysis and improvement phase of the model. Each value of the eleven program objectives must be within the program's (or its customers') specification limits. The analysis process is a reverse process to one that is used to construct the final report. Assume that the value of the program outcome "d" is below the LSL and the process is out of control. The assessors then, check the program outcome evaluation reports by: alumni, employers, professors (portfolio) and senior students (students exit interviews) for program outcome "d", using the specification limits exclusively developed for each of the reports. One or more of the reports (for example Report 5 in Table 6) will show that program outcome "d" in that report is below the satisfactory level. After the assessment material review it has been found that the employers' evaluation report exhibited an unsatisfactory level. According to Table 3, the value of program outcome "d" is the result of data gathered form questions 9 and 12 of the employer survey. To narrow down the problem the assessors will analyze the other relevant reports. For example, Figure 1 shows students' performance in the area of engineering science. Most of the courses recorded setback in progress over the past three years. Course 20INDS452 is the only one that shows progress in last year. It also appears that the courses 20INDS411 and 20INDS454 exhibit the lowest overall score performance.

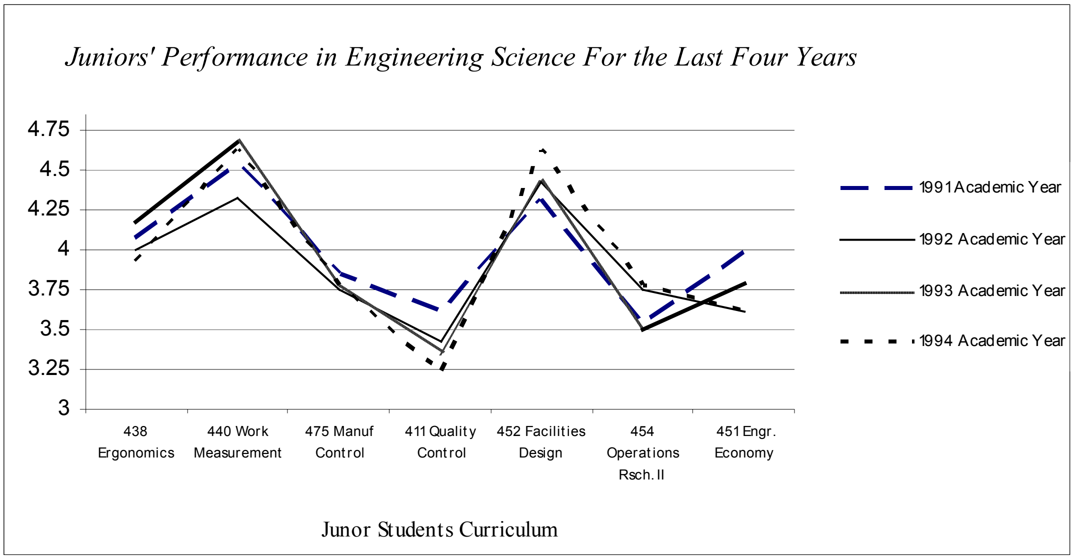

Figure 1. Portfolio Aspect VIII Review - Junior Students Engineering Science Abilities

These findings initiate the next phase of the model – designing and implementing effective improvements so that the program meets its outcomes and the customers' requirements.

"Implementation" Phase

Measurements are important to the effectiveness of a Six Sigma program. However, measurement by itself does not fix anything [15]. Moreover, it can reduce the effort if the organization spends considerable time and money collecting and analyzing data. The major value of a Six Sigma program should be the use of statistical techniques and the application of "continuous improvement" concept. If this is the focus of a Six Sigma initiative, customer satisfaction, cycle times, defect rates, and so on, will improve [15]. After the collected data is analyzed and conclusions are reached, the solutions must be implemented so that the overall process is improved (continuous improvement). In the implementation phase faculty together with other assessment team members will identify and implement solution for implementation of learning outcomes.

Implementing Improvements

This is the phase where all the work of Defining, Measuring, and Analysis process problems pays off. Six Sigma is usually a combination of ideas that together make up a plan for results, whether it is a changed course outline, curriculum, implementation of new teaching techniques, enhanced service delivery to the students and external customers, etc. Less often but equally important there is a need for reconstructing a program's curriculum, especially if the same problem is detected within different courses. Since co-op employers have detected the problem discussed above they should be part of the solution too. Faculty must also play a major role in program improvement. These are the people who will initiate and implement necessary changes with respect to the above questions.

"Control" Phase

Following the implementation phase the process has hopefully improved. At this stage it is essential to institute steps that guarantee stability in the system – that is the process must be controlled and stabilized so that it can stay at the newly improved level until the next cycle begins. Final goal of an engineering program is to achieve its program objectives and program outcomes. In the control phase the emphasis is on the activities which help to control educational system that is in place as well as techniques to further develop and qualify potential solutions. Appropriate statistical process control (SPC) tools need to be used as screening techniques. The faculty and college administrators must implement measures that will control the key variables within the operating limits. The example described below is only one way of controlling the key variables for program outcomes of an engineering program. In some other instances it will be simply the matter of managing the processes in higher business level.

Control of the Process

In the course of measuring and analyzing an assessment process, it's often possible to draw valid conclusions simply by looking at the data. The fact is, however, that in many instances, the so-called "patterns" we think we see are simply random variations [[28]]. Tests of Statistical Significance are very important techniques used to detect patterns or to test the quality of data. Analysis of Variance (ANOVA) is a very important test of Statistical Significance. It is the test of significance for continuous data that can be used to compare more than two groups of data.

Using one-way ANOVA it is possible to conclude, for example, whether there is a sufficient amount of evidence to conclude that population means differ with respect to knowledge that students are required to demonstrate regarding the program objectives.

Nevertheless, before this technique is used it is imperative to determine whether or not the comparison of all the courses will be useful to the evaluators. This primarily depends on the nature of the courses compared.

Conclusion

Using Six Sigma methodology to improve the quality of engineering education is a superior approach to the problem and may be applied to any engineering college settings in order to support continuous quality improvement. The model presented in the paper is a comprehensive guide to the real world application of Six Sigma in academia. It describes how this powerful methodology may be applied to any engineering program in order to offer high quality service for its internal as well as external customers. At the same time the model is designed to provide a detailed roadmap for assessment for an engineering program seeking ABET EC 2000 accreditation.

However, the issue of faculty participation has to be at the heart of any assessment model to be successful. Without the full participation of faculty no model, no matter how comprehensive, will be beneficial.

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