Engineeering the Accreditation Process

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Engineering the Accreditation Process

The similarities and differences between ABET engineering accreditation criteria (otherwise known as EC-2000) and ISO 9000, the quality assurance standard in industry, have been discussed and documented since the initial public review of EC2000.[20] ISO 9000 is a quality management system (QMS), where a QMS is defined as "coordinated activities to direct and control an organization with regard to achieve quality objectives," where quality is defined as "the degree to which a set of inherent characteristics fulfills a need or expectation."[7] The adoption of a QMS helps an organization improve its overall performance and provides a sound basis for sustainable development initiatives. Quality Management is an area within the Industrial Engineering Body of Knowledge [13] and often a required topic in industrial engineering curricula. Most engineering education articles and research on EC 2000 have focused on the assessment of outcomes a – k, designing courses to satisfy EC 2000, or the impact of EC 2000[12, 14, 17, 21, and 2]. None have used the similarities between EC2000 and QMS to identify and use the tools of quality and industrial engineering to design and document the processes that satisfy the ABET Engineering Accreditation Criteria. The objective of this paper is to present how several quality and industrial engineering tools, most of which are graphical, can be used to develop, implement and improve an engineering program as a quality management system. Due to the graphical nature of the tools, they are also effective at demonstrating compliance to the ABET engineering accreditation criteria in a program's Self Study Report.

The first section of the paper provides the context of how the ABET Criteria for Accrediting Engineering programs evolved into a QMS. The second section maps the Criteria to the ISO QMS model. The third section describes an engineering program as a process that can be improved to achieve desired results. The fourth section explores how the concepts and tools of quality and industrial engineering can be used to satisfy the Criteria, criterion by criterion. The last section will summarize results of applying the tools in both established and new industrial engineering programs.

History of Continuous Quality Improvement and ABET [18]

From its very beginnings in 1932, ABET (originally known as the Engineer's Council for Professional Development or ECPD) has been focused on improvement of engineering education. It was established in 1932 "as a cooperative movement for **improving** the selection, education, post college training, and method of recognizing attainment of engineers." ECPD's role in engineering accreditation grew and evolved as two world wars and resulting technological developments changed the world and engineering education shifted from an applied, practice-oriented focus to a mathematical academic engineering science focus. Over the years the criteria grew from just under three pages to 12 full pages with an additional 14 pages devoted program criteria required for individual engineering disciplines. The unintended consequence of this growth was to make program evaluation more mechanical with decreased opportunity for professional judgement by the program evaluator (PEV) and to discourage innovation in engineering programs, for fear such innovations would jeopardize accreditation. By the late 1980s engineering employers and educational leaders recognized that preparing engineers for 21st century practice demanded fundamental changes in the engineering science paradigm.

ABET was perceived as an impediment to innovation. Presidents of the University of Michigan, and MIT publically stated that engineering education must change to support the new **quality-oriented environment** and that ABET's rigid "bean counting" posed a significant barrier to needed innovation. Similar concerns were echoed by ABET's Industry Advisory Council and deans of major engineering schools in 1992.

Fortunately, ABET listened. An Accreditation Process Review Committee (APRC) composed of academic and industry leaders, leaders from ABET and the Engineering Accreditation Commission (EAC) was chartered to advise on how to increase flexibility in the engineering accreditation criteria while maintaining a strong emphasis on educational **quality** and to recommend ways to facilitate recruitment of outstanding engineers from industry and education to lead the ABET accreditation process. The committee identified three major barriers to change: 1) excessively long, prescriptive and detailed accreditation criteria, 2) a complicated and user-unfriendly evaluation system, and 3) difficulty attracting technically active mid-career professionals. ABET with support from the National Science Foundation convened consensus-building workshops involving stakeholders from industry, academia and professional societies which led to the publication of *The Vision for Change* in 1995 which called for fundamental changes in accreditation criteria, evaluation procedures and selection and training of evaluators. In October 1995, the ABET Board of Directors approved *Engineering Criteria 2000 (EC2000)*. The criteria placed a strong emphasis on the definition of program objectives and student outcomes. At the heart was a **continuous improvement** process for program improvement.

These criteria became mandatory for all general reviews in 2001. Bob Furgason, ABET President 1993-94 lists "the development of outcomes-based approach to assessment as the **most significant action** involving **quality control** in the history of engineering education." Actions to attract and train technically active mid-career professionals as ABET evaluators would take longer. The Participation Project and its successor, Partnership to Advance Volunteer Excellence (PAVE) continued the collaboration between member societies, volunteers, and headquarters staff to advance ABET's commitment to **continuous quality improvement** of its volunteer processes beginning in 2003. PAVE led to a program evaluator competency model, new experiential volunteer training, workshops on assessment, and a new volunteer management tool. Further demonstrating commitment to **continuous quality improvement**, ABET was formally recognized as ISO 9001:2008 certified in 2015.

Engineering Criteria as a Quality Management System

The ABET Engineering Criteria (and by association, the Engineering Technology, Applied Science and Computing Criteria) [2, 3, 4, and 5] define an educational quality management system (QMS). According to ISO 9000:2008, a QMS is "coordinated activities to direct and control an organization to achieve quality objectives," where quality is defined as "the degree to which a set of inherent characteristics fulfills a need or expectation."[7] The QMS described in ISO 9001:2008 and 2015[7, 8] is based on six quality principles: customer focus, leadership, engagement of people, process approach, improvement, evidence-based decision-making and relationship management. ISO 9000:2005 provides a model for a process-based QMS that depicts the interrelated elements that comprise a QMS (see Figure 1) [7].

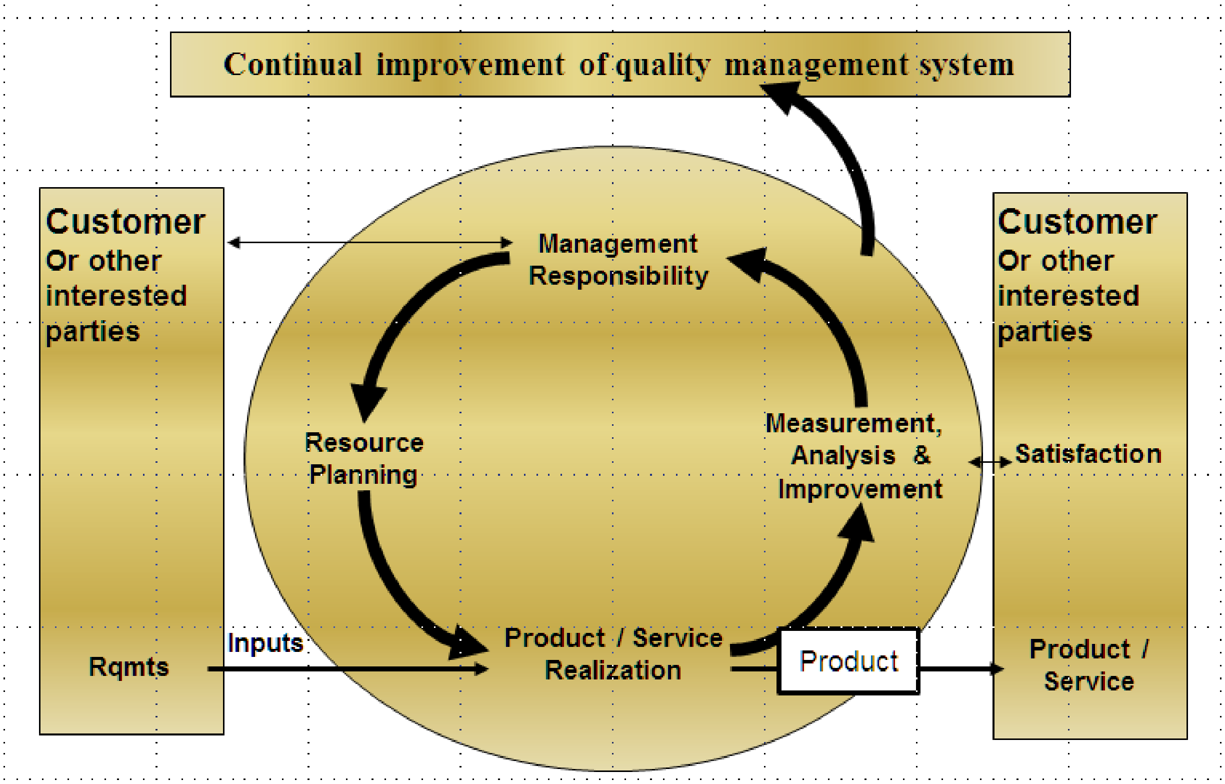


Figure 1: Model of process-based quality management system [7]

The 2017-18 Engineering Criteria state the "criteria are intended to assure **quality** and to foster pursuit of improvement in the quality of education that satisfies the needs of constituencies …" Therefore, the process-based quality management system model and principles can be extended to the Engineering Accreditation Criteria in which the elements are: constituents, curriculum, faculty, assessment, facilities, and leadership (support). The resulting model is shown in Figure 2.

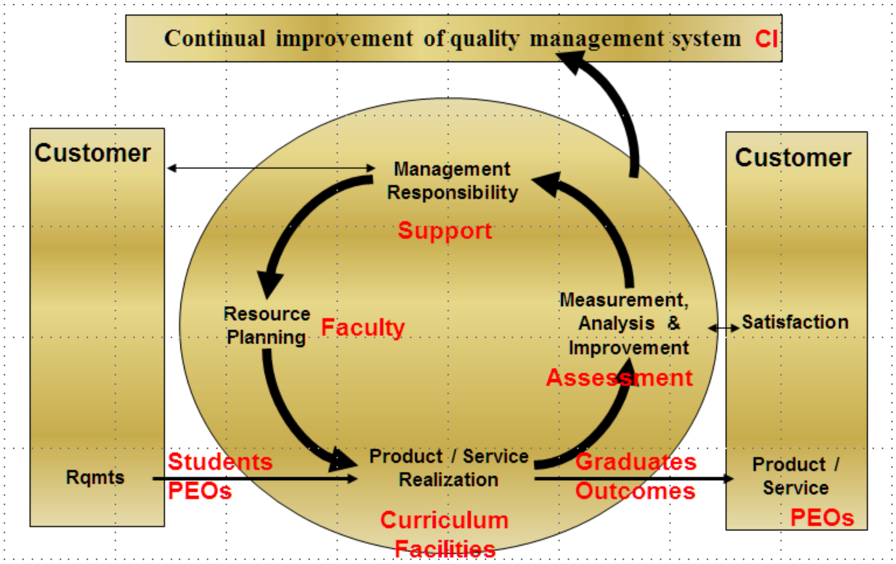


Figure2: ABET Engineering Accreditation Criteria of process-based quality management system Model

Depicting the ABET Engineering Criteria in this way allows us to recognize the parallels between the individual Engineering Criteria criterion and the elements of ISO 9001:2015 [8]. This in turn allows us to apply the tools and concepts of quality to each Criterion.

Engineering Program as a Process

ISO 9001:2015 "promotes the adoption of a **process** approach when developing, implementing and improving the effectiveness of a quality management system. The process approach involves the systematic definition and management of processes and their interactions so as to achieve the intended results."[8] Such an approach enables:

- **a.** understanding and consistency in meeting requirements;
- **b.** consideration of processes in terms of added value;
- **c.** achievement of effective process performance; and
- **d.** improvement of processes based on evaluation of data and information.

Process thinking is a key concept of industrial engineering, where a process is defined as a series of steps/activities that transforms inputs into outputs (see Figure 3) [15]. Delivering an engineering program can be viewed as a process where students are transformed into graduates/alumni. Accreditation of a program involves design, implementation and improvement processes for each of the criterion. For example, Engineering Accreditation Criteria 2 and 4 require that a program have **processes** in place. We will consider how to apply the industrial engineering and quality system process concepts and tools related to designing and describing these processes in the next section.

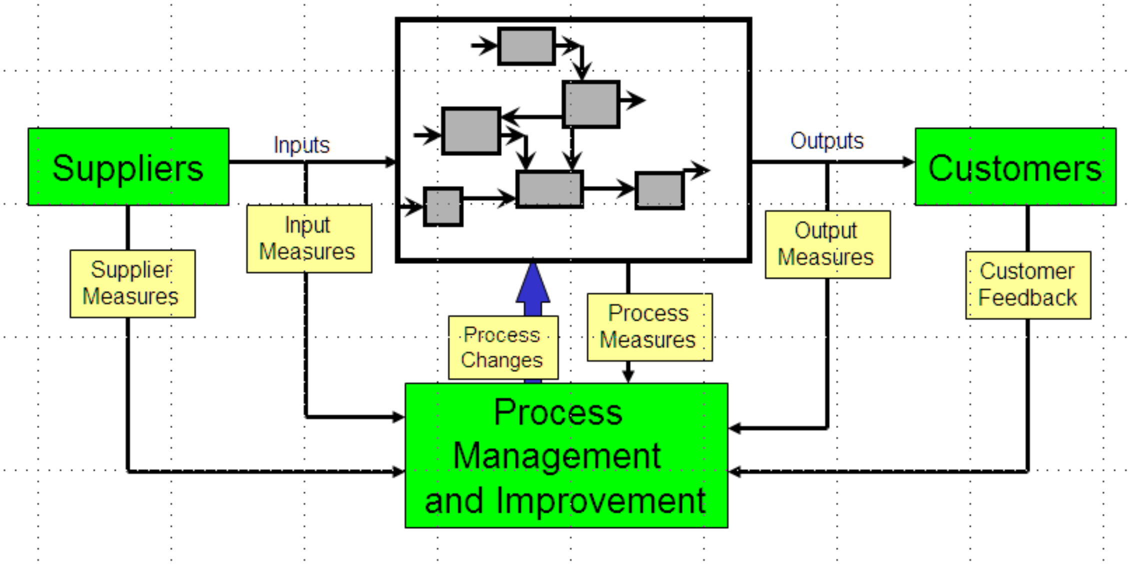


Figure 3: Graphical View of a Process

Applying QMS and Process-Approach to Engineering Criteria by Criterion

We will explore how to use quality and process concepts and tools to each of the criterion in this section.

Criterion 1: Students

Quality output is a function of the inputs and process design. Using this concept, the performance requirements of the inputs must be are known and met to ensure quality output. Using concepts of process control, the requirements should be set to ensure that the process can produce output that meet the needs of the customer. With respect to Criterion 1, Students, this implies that the requirements for admission be set to ensure the program will produce graduates that attain the student outcomes and that there are policies/procedures in place to ensure students meet these requirements to enter the program. Think of this as feedforward control.

Student transcripts serve as the official record of student progress through the program and provide evidence that the policies/procedures are being followed. The degree audit performed prior to graduation is an internal audit to determine whether or not the policies/procedures are implemented, maintained and working properly, not just that an individual student met all the requirements. Good audit practice such as independence of the auditor and documentation of the audit should be followed.

Criterion 2: Program Educational Objectives

ABET defines Program Educational Objectives as “broad statements that describe what graduates are expected to attain within a few years of graduation; program educational objectives are based on the needs of the program’s constituents.” The program constituents are interested parties, person or groups having an interest in the performance or success of the program. Strictly using this definition, constituents of an engineering education program, may include alumni, employers, local industry, faculty and students. However, faculty and students are internal to the program and may have limited perspective of what graduates are expected to attain a few years after graduation, with the exception of faculty in a program with a high percentage of its graduates continuing in graduate studies. The input/perspective of both faculty and students is important for improvement of the program and will be considered in Criterion 4. A program can identify these objectives using voice of the customer tools such as focus groups, surveys, one-on-one interviews and/or ethnography to identify and understand constituent needs. The information/data from these interactions can then be clustered using an affinity approach to identify and concisely state the unique needs of the program’s constituents. A SMART (Specific-Measurable-Actionable-Realistic-Time-based) structure is helpful in stating the PEOs in concise form. While the Engineering Criteria no longer requires measurement of the PEOs, stating the PEOs in a way that is measureable makes them more tangible and understandable to the public (the program must publicly state the program’s educational objectives)[1].

Criterion 2 also requires that the program have a documented, systematically utilized and effective **process**, involving program constituents, for the periodic review of the PEOs. In keeping with the definition of a process, a program should state the steps in the process, the responsibility and timing/frequency of each step when describing the review process in the Self-Study Report (SSR). This could be done using a swim-lane flowchart [9] that shows the steps, sequence, responsibility and timing in one diagram or a table listing the steps, responsibility and timing/frequency for each step. The flowchart or table should be included in the Self-Study Criterion 1 Section to describe the process; this would require less text and be easy for the program evaluator to follow ("a picture is worth a thousand words").

Criterion 3: Student Outcomes (SOs)

ABET defines student outcomes as "what students are expected to know and be able to do by the time of graduation; these relate to the skills, knowledge, and behaviors that students acquire as they progress through the program." The EAC defines student outcomes as a – k for all engineering programs. Using process thinking, student outcomes are the requirements/specifications that the output must meet at final inspection. Student outcomes must prepare graduates to attain the PEOs. A simple L-shaped matrix [9] mapping the relationship between PEOs and a-k shows how SOs contribute to the attainment of the PEOs. In the rare event a program completes such a matrix and finds that one or more of their unique PEOs does not map well to a-k, it may choose to add SOs. SOs beyond a-k, however, must be assessed and evaluated to determine the extent attained in order to be in compliance with Criterion 4.

Criterion 4: Continuous Improvement

Criterion 4 requires the program "use appropriate, documented **processes** for assessing and evaluating the extent to which the SOs are being attained; the results of these evaluations must be **systematically** used as input for continuous improvement of the program." Per the definition of process, this implies that the program should describe its program assessment, evaluation and corrective actions by stating the steps in the process, the responsibility and timing/frequency of each step. A swim-lane flowchart that shows the steps, sequence, and responsibility in one diagram (see sample in Figure 4) or an L-shaped matrix [9] listing the steps, responsibility and timing/frequency for each step could be used for this description (see Table 2). Note that not all steps need to be done every year; two complete cycles within a six year accreditation cycle are generally viewed as acceptable. Every SO does not need to be measured each semester either; that is considered unsustainable. (see Table 3 for a sample schedule for a six-year accreditation cycle). An SO that does not meet the targeted level of attainment, requiring corrective action, may trigger more frequent data collection.

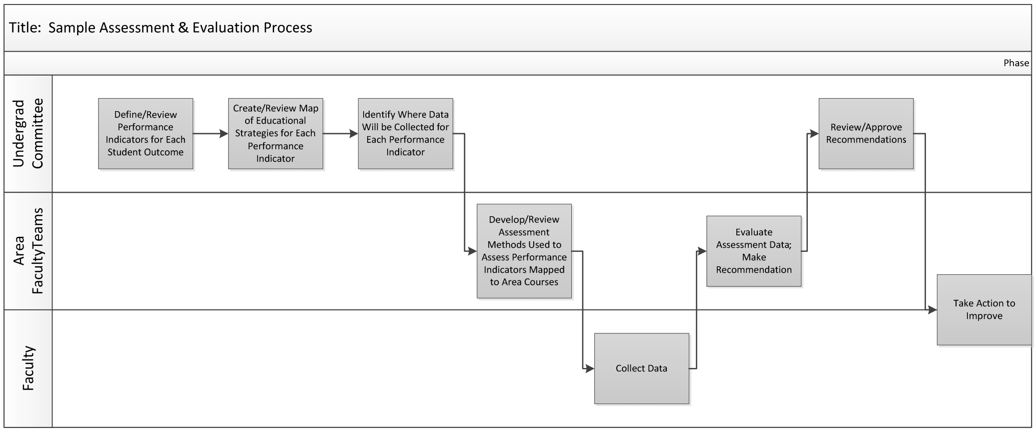
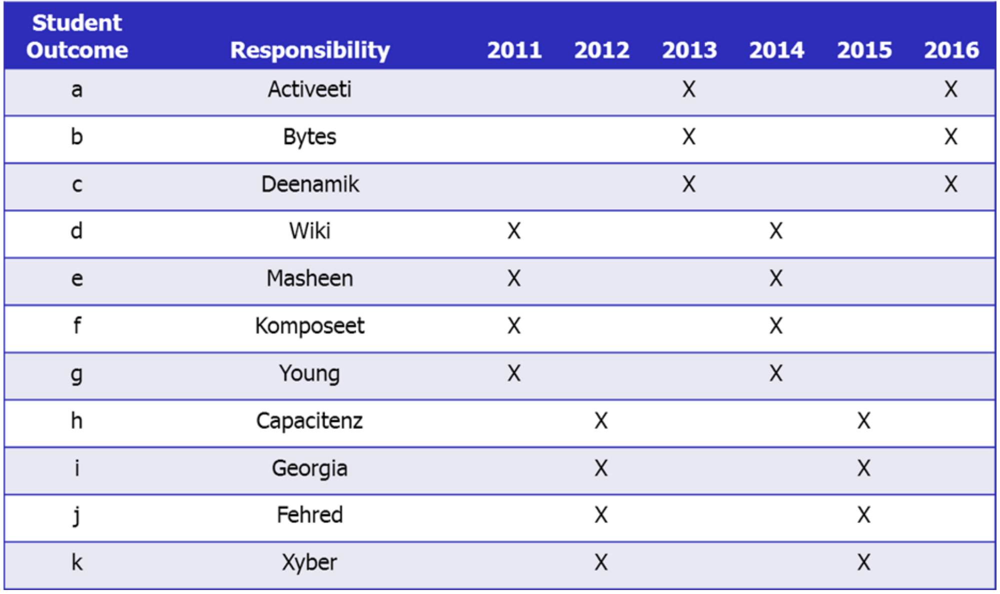


Figure 4: Sample Assessment & Evaluation Process in Swim Lane Flowchart Format

Table 2: Sample Assessment & Evaluation Process in Matrix format[6]

Activity	Responsibility	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Define/Review performance indicators for the outcomes	Undergraduate Committee	x			x		
Create/Review map of educational strategies related to performance indicators	Undergraduate Committee		x			x	
Define/Review mapping and identify where data will be collected	Undergraduate Committee		x			x	
Develop/Review assessment methods used to assess performance indicators	Area Faculty Team		x			x	
Collect data	Faculty			x			x
Evaluate assessment data including processes	Undergraduate Committee			x			x
Report findings	Undergraduate Committee			x			x
Take action where needed	Area Faculty Team, Faculty			X			X

Table 3: Sample Student Outcome Assessment Frequency[6]



Student Outcome	Responsibility	2011	2012	2013	2014	2015	2016
a	Activeeti			X			X
b	Bytes			X			X
c	Deenamik			X			X
d	Wiki	X			X		
e	Masheen	X			X		
f	Komposeet	X			X		
g	Young	X			X		
h	Capacitenz		X			X	
i	Georgia		X			X	
j	Fehred		X			X	
k	Xyber		X			X	

Students acquire the outcomes as they progress through the program. Staying with our process view of accreditation, assessment is on the final "product" or the student by the time of graduation. By definition then, the assessment of SOs should be summative or measured in courses during the final year of the program. Formative measures earlier in the curriculum, faculty observation and student self-evaluation can and should be used to confirm patterns/trends so that the program responds to SOs below targeted level of attainment with a sense of urgency to improve the program. Using visual management techniques of Lean Manufacturing, results of both summative and formative assessment can be organized and displayed in a prominent location within the program for all faculty, staff and students to see [16]. This approach will engage all faculty members in the continuous improvement process whether or not they teach courses in the final year of the program.

Criterion 4 also states that "other available information may be used to assist in the continuous improvement of the program." In other words, the program can use feedback and observations from faculty, staff and students to ABET states "effective assessment is a process that uses relevant direct, indirect, quantitative and qualitative measures appropriate to the outcome being measured. Appropriate sampling may be used as part of an assessment process." To create an effective assessment process that can be used to monitor and improve performance, it is necessary that: 1) the process include sound measures to monitor the right things 2) there be a total measurement system, not a collection of unrelated measures, and 3) the data is converted into **intelligent action** [19]. Sound measures are indicators of the critical dimensions of the process (SOs) and answer the question "What indicators will tell us if our students have attained this SO?" This approach is output-driven and customer focused (process and quality principles).

Most outputs have more than one critical dimension that must be measured. The same is true for the Engineering Student Outcomes a-k as several include more than one dimension (highlighted with an "and"):

a) Ability to apply knowledge of mathematics, science, **and** engineering.
b) Ability to design **and** conduct experiments, as well as analyze **and** interpret data.
c) Ability to design, develop, implement **and** improve a component, process, or integrated system of people, materials, information, equipment, **and** energy to meet desired needs within realistic constraints (such as economic, environmental, social, political, ethical, health **and** safety, manufacturability, and sustainability).
e) Ability to identify, formulate, **and** solve engineering problems.
f) An understanding of professional **and** ethical responsibility.
h) Broad education to understand the impact of engineering solutions in a global, economic, environmental, **and** societal context.
i) A recognition of the need for, **and** have the ability to engage in life-long learning.
k) An ability to use the techniques, skills, **and** modern engineering tools necessary for engineering practice.

This means that a program will need more than one indicator (summative measure) for eight of the eleven SOs. Sample performance indicators for outcomes (b) and (e) are shown below in Table 4.

Table 4: Sample performance indicators for Student Outcomes (b) and (e)[6]

Student Outcome	**Performance Indicators**
b) an ability to design and conduct experiments, as well as analyze and interpret data	• Determines data needed and selects appropriate equipment / protocols for data collection. • Observes good lab practice and operates instrumentation with ease • Uses appropriate tools to analyze data, including use of statistics • Verifies and validates experimental results
e) an ability to identify, formulate, and solve engineering problems	• Problem statement shows understanding of the problem • Solution procedure and methods are formulated • Problem solution is appropriate and within reasonable constraints.

While a Gage R&R study is not required for SO data collection and evaluation, good measurement system practices should be applied, such as operational definitions, sampling, and reproducibility of measurement between two or more assessors [12]. Good operational definitions are needed to ensure consistent measurement and evaluation over time. While included in the Engineering Student Outcomes, ABET does not define multidisciplinary teams (d), contemporary issues (h), life-long learning (i), or modern engineering tools (k). Since ABET does not define these terms, it is up to the program to define them in the context of their unique PEOs and identify indicator(s) appropriately for consistent decision-making (otherwise risk Type I or Type II errors). Care should also be taken not to combine assessment data from different levels of maturation of student knowledge, skills and abilities. “Scores” for individual SO attainment should not be calculated by averaging formative and summative assessment data. By definition, SOs should use summative assessments only.

Criterion 4 also states that “other available information may be used to assist in the continuous improvement of the program.” In other words, the program can use feedback and observations from faculty, staff and students to improve all aspects of the program (admissions, advising, faculty development, facility maintenance), including the continuous improvement process.

Criterion 5: Curriculum

Using process thinking, the curriculum is the process through which students are transformed into graduates that attain the student outcomes, enabling them to attain the program educational objectives. Each course in the curriculum is a step in the process that contributes to the attainment of the student outcomes. The sequence of courses and individual course learning outcomes should be designed to accomplish this within the Engineering Criteria constraints. The constraints are that the curriculum include one year of a combination of college level mathematics and basic science (32 credits), one and a half years of engineering topics (48 credits), a general education component that complements the technical content, and a culminating major design experience. Thus the curriculum is a designed process with constraints that may be depicted in flowchart format, to show the prerequisite structure.

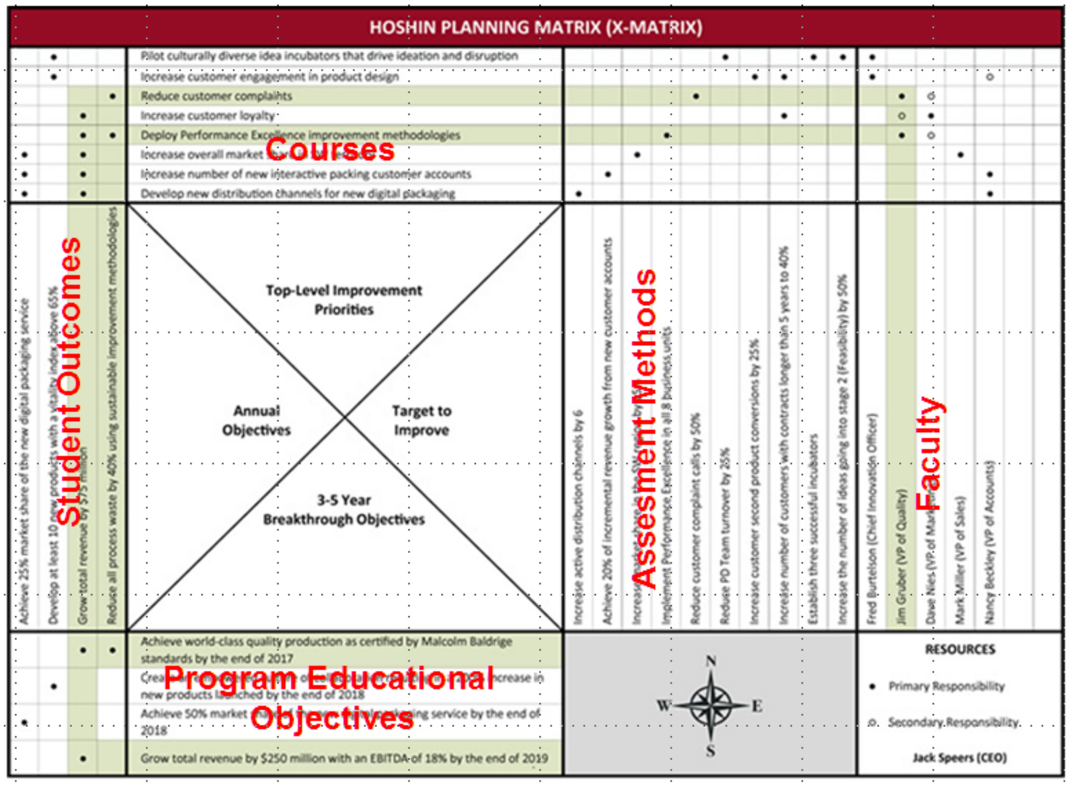
Criterion 6: Faculty

Engineering Criterion 6 requires the program have sufficient faculty to cover all curricular areas of the program, to accommodate adequate levels of student-faculty interaction, student advising and counseling, service activities, professional development, and interactions with industrial and professional practitioners, as well as employers of students." This aligns with the ISO 9001:2015 requirement that "the organization determine and provide persons necessary for the effective implementation of its QMS and for the operation and control of its processes." One process-oriented way of identifying the number of faculty needed to deliver the program is by mapping the relationships between faculty, courses and assessment; gaps can easily be identified as input for faculty development and recruitment.

Program Educational Objectives, Student Outcomes, Continuous Improvement Curriculum and Faculty (Criteria 2- 6) together form a planning system for the program. One potential way to represent this system is through a Hoshin Kanri matrix, a Lean Manufacturing strategic planning tool [10] (see Figure 4). The resulting matrices at the intersection between pairs of the five components can be used to describe the processes used for assessment that tie courses to student outcomes and in turn to program educational objectives and faculty and be included in the Criterion 2, 3, 4, 5 and 6 Sections of the Self-Study.

Engineering Criterion 6 also requires faculty have appropriate qualifications, where competence may be judged by such factors as education, participation in professional societies and licensure. The program must also demonstrate the faculty have sufficient authority to ensure proper guidance of the program. Both of these can be demonstrated using the Hoshin Kanri matrix by adding rows/columns intersecting the faculty rows

Figure 4: Hoshin Kanri Matrix for Criteria 2 - 6



Criterion 7: Facilities

ISO 9001:2015 states “The organization shall determine, provide and maintain the **infrastructure** necessary for the operation of its processes to achieve conformity of products and services”. [8] If you replace infrastructure with “classrooms, offices, laboratories, and associated equipment” and conformity of products and services with “attainment of student outcomes and an atmosphere conducive to learning,” you have Criterion 7. Looking at facilities through the eyes of the ISO 9001 QMS model, facilities play a supportive role; facilities are determined based on the needs of the process, not the other way around as programs often do. The process model can be used to identify the “inputs” or classrooms, offices, laboratories and associated equipment necessary to deliver the program. Once those inputs are known, then the maintenance and replacement planning needed to keep the facilities in good working order to ensure the attainment of student outcomes and an atmosphere conducive to learning can be specified using risk-based thinking to address potential failure modes with the equipment / facilities.

Most programs, however, have existing facilities. This perspective calls the program to evaluate its existing facilities and remove/declutter/consolidate/rearrange facilities to better enable attainment of student outcomes. Research and graduate program facilities can be evaluated in the same manner and plans combined as appropriate. Facilities can be added to the Hoshin Kanri matrix and mapped to courses that are in turn mapped to student outcomes. The exercise of completing this evaluation will create a dialog within the faculty to further clarify the relationships between the curriculum, student outcomes, and facilities.

Criterion 8: Support

Criterion 8 states that "institutional support and leadership must be adequate to ensure the **quality** and continuity of the program." ISO 9001: 2015 5.1 requires management demonstrate leadership and commitment with respect to the QMS by10 possible actions, including ensuring quality objectives (PEOs) are established, resources (services, finances, faculty and facilities) are available, and engaging, directing and supporting persons to contribute (professional development of the faculty) to the effectiveness of the QMS [8]. Once again, the process model can be used to identify the "inputs" or services, finances, faculty and facilities needed to deliver the program in an environment in which student outcomes can be attained.

Result of Appling Quality and Industrial Engineering Tools in Accreditation

The tools described above and the model of the ABET engineering accreditation criteria as a QMS have been shared with multiple programs, both those accredited for decades and newly accredited programs as part of the author's ABET accreditation consulting. Industrial engineering faculty members have responded favorably to the model and use of the tools, and designed or modified their processes to incorporate the model and tools. An established industrial engineering program at a large state-related research institution was successfully re-accredited under EC 2000 two times since implementing the model and tools. The program evaluator of the most recent evaluation commented that it was the best documented and easiest to understand assessment process that he had seen in his twenty-plus years as a program evaluator and team chair. The program's ABET coordinator is preparing to retire at the end of the Spring 2016 semester and is confident another faculty member can easily pick up the reins and continue to use the model and tools for ABET accreditation. Three new industrial engineering programs seeking initial accreditation were successful in achieving accreditation with no shortcomings on their first evaluation after implementing the model and tools.

Summary

The ABET Engineering Accreditation Criteria form a quality management system that can be mapped to ISO 9001:2015. Like ISO 9001:2015, the Criteria use a process-approach to develop, implement and improve the effectiveness of an engineering program. This means that tools of quality and industrial engineering can be used to design and document the processes that satisfy the Criteria. Using the graphical tools discussed in this paper to develop, implement and improve an engineering program is a powerful way to document the program's quality management system in its Self Study Report and ensure a successful ABET accreditation evaluation.

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