# A Systems Approach to Accredited Program Accountability in Regional Universities

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## Abstract

Broadly stated, academic degree program accountability measures value created versus cost. Value is determined by social and economic needs of the community, state, and region. Costs reflect resource requirements to address complex endogenous and exogenous challenges that require strategies for allocating resources, and monitoring and adapting strategies to ensure accountability.

Program accountability is also important in flagship institutions. However, small perturbations in degree programs strategies of flagship institution can be major problems for regional universities because of insufficient resources to quickly adjust for unintended consequences of these strategies. The signature of engineering degree programs in regional universities is graduating successful practicing engineers and mid-level managers for regional companies and regional operations of larger companies from a student population that includes a significant number of rural and frequently less academically prepared students. An engineering curriculum that satisfies ABET General criteria and meets academic needs of students from a diverse and time variant student profile in a regional university creates uniquely challenging problems.

This paper proposes a W. Edwards Deming's System of Profound Knowledge (SPK) that extends program accountability embedded in the ABET General Criteria by developing metrics for academic program efficiency and effectiveness; compressing time to collect, summarize, and analyze program data; and identifying at-risk students in a timely manner. Program efficiency measures levels of non-value added activities consuming academic program resources. In contrast, effectiveness measures attainment levels of ABET defined student outcomes and program objectives.

The additional industrial engineering and engineering management tools and techniques incorporated into this SPK address accountability and program effectiveness limitations in a previously developed ABET accreditation platform that received critical acclaim. These SPK concepts are easily extendable to science, technology, engineering, and mathematics (STEM) programs.

## I. Introduction

### Regional Program Accountability

Broadly stated, academic degree program accountability is value created versus cost. Value reflects social and economic needs of the community, state, and region. Costs are resource requirements to implement departmental strategies. Academic degree programs face increasingly complex endogenous and exogenous challenges affecting program accountability that include technological changes, financial stability, and demographic shifts in student populations. Entirely related is Buhrman's discussion [1] on accountability that includes documenting formative and summative assessment techniques to evaluate instruction.

Elizandro et. al. developed a vertically integrated approach to stakeholder engagement in regional university accountability [2] that originates from this proposed implementation strategy for ABET accredited programs. However, the concept is easily extendable to all science, technology, engineering, and mathematics (STEM) programs [3]. STEM program accountability is critical because of the regional university roles in the economic development engine for the region and state. There is implied competition between states for increasing the number of STEM graduates. Enrolling more students in these programs dramatically alters the academic profile of a regional university student population and affects the resource allocation strategy to academic programs.

The accountability issue is applicable to both regional and flagship institutions. However, the signature of engineering degree programs in a regional university is graduating successful practicing engineers and mid-level managers for regional companies and regional operations of larger companies from a student population that includes a significant number of rural and frequently less academically prepared students.

The university, college, faculty, and students are internal stakeholders vested in academic program accountability. Because of the regional employment of most graduates, degree program advisory board members from these organizations provide invaluable perspective on regional and state stakeholder accountability concerns. ABET is a degree program stakeholder because accountability is the basis for ABET accreditation.

**Regional University Conundrum**

Regional public colleges and universities have been described as "the 'undistinguished middle child of higher education,' squeezed on one side by community colleges and on the other by flagship universities" [4]. Although there are similarities, regional engineering programs are very different from programs in a flagship institutions. An engineering curriculum that satisfies ABET General criteria and meets academic needs of students from diverse and time variant student profiles in a regional university creates uniquely challenging problems. Therefore, assuming institutional strategies are easily transferrable between the two is problematic.

Another difference between regional and flagship institutions is the extent alternative strategies are applied to creating and administering institutional revenue streams. Regional universities rely more heavily on leveraging undergraduate programs as an incremental revenue source for other initiatives. Variations of these strategies create small perturbations in flagship institution degree programs but can significantly affect the stability of academic programs in regional universities. Insufficient resources are problematic for quickly adapting strategies to support academic programs that suddenly become unstable because of leveraged undergraduate degree programs.

Common approaches to leveraging degree programs are increasing the number of adjunct faculty, reducing the number of course sections, administering an aggressive student recruiting strategy and reducing the number of elective courses. Adjunct faculty are a viable option for increasing breadth and the depth of the body of Knowledge (BOK) [5] in the discipline. However, accessibility to adjunct faculty is usually problematic for regional universities.

Another potential problem is leveraging undergraduate programs to develop undergraduate research programs with small classes for the top 15-20% of the student population. This strategy has the potential for creating a large number of academic orphans. While none of these strategies are de facto problematic, regional university academic programs with a heterogeneous student profile are much more sensitive to the trade-offs of leveraging. Acknowledging these institutional differences is essential for developing strategies to ensure degree program accountability.

**Academic Profile of Engineering Students**

The primary discernable difference is the academic profile of students. The student profile in a regional university is much more heterogeneous. Elizandro, et. al. demonstrated that an aggregate analysis of a heterogeneous population profile in a regional university masks differences apparent in population subsets [6]. In the analysis of student success in an introductory CEE 2110 engineering mechanics course, the population of students in the course was divided into the following four mutually exclusive categories based on ACT scores.

- Core Students with ACT scores ≥ *25* who are adequately prepared to begin engineering degree coursework.
- Mission Specific Students with ACT scores ≥ *22* and < *25* who, with mentoring, should be able to complete engineering degree requirements.
- At-Risk Students with ACT scores < *22* who may have difficulty mastering a college of engineering curriculum.
- Unknown-Risk Students who are transfer students not required to submit ACT test scores and international students without an ACT score.

Identifying at-risk students and/or academic program issues that affect student success are critical components of accountability in regional degree programs. To adequately serve these students, as well as the region and state, degree programs must include processes that minimize academic program discontinuities by advising students on other degree programs and academic institutions that better match their interests and needs. An ad hoc *management by exception* strategy whereby an organization reacts to exceptions in expectations exacerbates problems. A dynamic response requires leadership adept at establishing a well-defined academic programs, monitoring degree program, and as necessary, adapting strategies to ensure degree program accountability.

The Pareto Distribution, commonly known as the 80% - 20% rule is applicable to detecting problems with perception within an academic degree program. For example, traffic laws cannot be enforced effectively without voluntary compliance of the majority. US Department of Transportation traffic engineering heuristics set speed limits at the 85$^{th}$ percentile of speed based on the principle that speed of a reasonable person should be legal [7].

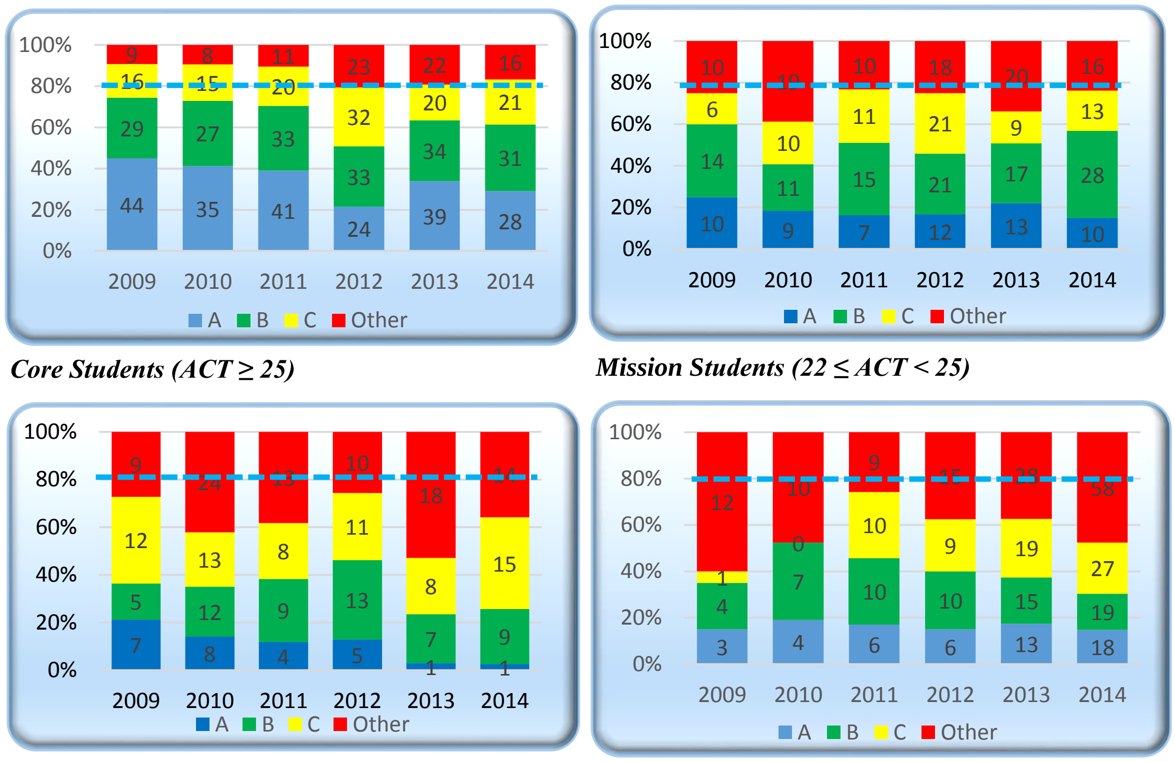
Based on experience of faculty teaching the civil engineering mechanics courses, a course becomes unstable when favorable perception of the course by students is below the 85$^{th}$ percentile. Symptoms of unfavorable perceptions are an excessive number of students performing poorly in courses, higher incidences of academic dishonesty, poor class attendance, and poor faculty evaluations indicating student frustration in a course.

Figure 1 presents the number of D/W/F grades in the engineering mechanics course by the above strata. For visualization, grades are color coded and shown as cumulative percent. Codes are blue, green, yellow and red to represent *A*'s, *B*'s, *C*'s, and all other grades (primarily *W*, *D*, and *F*). Frequency counts are also included in each chart. The dotted line of the 80$^{th}$ percentile in Figure 1 indicates stability issues for at risk and unknown risk students. Almost half of At-Risk and Unknown-Risk Students earned grades below C.

| Classification Comparisons | P Value |
|---|---|
| Core Students (***ACT* ≥ 25**)<br>Mission Students (**22 <= *ACT*< 25**) | 7.8005E-07 |
| Mission Students (**22 <= *ACT*< 25**)<br>At Risk Students (***ACT* < 22**) | 0.001615887 |
| At Risk Students (***ACT* < 22**)<br>Unknown Risk Students (***No ACT***) | 0.087750273 |

***Table 1: Chi Square Pair-wise Classification***

Results of a pair-wise chi square analysis of grade distributions for student strata in Table 1 indicates significant statistical differences in spatial pairing of student categories. Grade distributions are statistically different for category 1 and 2 students. Grade distributions are also statistically different for category 2 and 3 Students.




*Core Students (ACT ≥ 25)*

*Mission Students (22 ≤ ACT < 25)*

*At-Risk Students (ACT < 22)*

*Unknown-Risk Students (No ACT)*

***Figure 1: CEE 2110 Grade Distribution by Student Classification Category***

To address accountability in regional university degree programs, the following sections present an organizational platform and related tools to administer accountability in a regionally ABET accredited program based on Deming's System of Profound Knowledge (SPK) [8]. For this paper, program accountability is defined in terms of degree program stability, program efficiency, as measured by levels of non-value added activities consuming academic program resources, and program effectiveness as measured by attainment levels of student outcomes and program objectives.

## II. Proposed *SPK*

### Overview

A regional university *SPK* consists of the following four components.

- ***Appreciation of systems***: Stakeholders (university, college, advisory board, ABET, faculty, and students) view activities as interrelated subsystems.
- ***Theory of knowledge***: Test opinions, theories, hypotheses, and beliefs against data to understand activity relationships and determine process improvement strategies.
- ***Knowledge of variation***: Ability to distinguish causes of measurement variation in activities, as well as predicting behavior, are essential for testing knowledge.
- ***Knowledge of psychology***: Understanding that stakeholders are motivated by intrinsic needs (pride in workmanship and working with others).

A compelling issue is the role of stakeholders in administering the SPK. Domain knowledge of stakeholders is the rationale for embracing a broader definition of accountability and expanded role for stakeholders in administering the SPK. In this context, crowdsourcing [9] is a request for stakeholder assistance with administering the SPK. Stakeholders provide invaluable perspective on regional and state accountability concerns with respect to program effectiveness. Crowdsourcing contributors are compensated by recognition and intellectual satisfaction of their effort. To facilitate stakeholder engagement, provisions of the Family Educational Rights and Privacy Act (FERPA) allow departments to disclose records, without consent, for academic program evaluation and accreditation [10].

A Balanced Scorecard is a closed-loop management system supported by design methods and automation tools utilized to facilitate monitoring academic program strategies [11]. The balanced scorecard focus is on a limited number of parameters to monitor academic program stability, efficiency, and effectiveness. Closed-loop implies performance data is compared to a reference value and depending on the magnitude of the difference, the implementation strategy for the academic program is modified.

SPK functional areas derived from the following ABET General Criteria [12] are:

1. **Students:** Ensure students are academically prepared and scheduled to be in the right place in the program at the right time.
5. **Curriculum:** Ensures an integrated set of courses and laboratory experiences from the discipline BOK to develop knowledge, skills, and behaviors of students and satisfies accreditation and university requirements.

**Extra-Curricular**, also an SPK Functional Area, consists of non-curriculum related program activities that also develop knowledge, skills, and behaviors of students. Examples of extra-curricular activities are student organizations and student conferences. SPK resources derived from definitions in the ABET General Criteria are:

6. **Faculty:** Ensure sufficient faculty with appropriate qualifications to teach the curriculum, accommodate university service, professional development, and interactions with industrial and professional practitioners as well as faculty authority to administer the program.
7. **Facilities:** Ensure classrooms, library services, offices, laboratories, and associated equipment provide a conducive learning environment for attaining student outcomes.
8. **Institutional Support:** Ensure institutional services, financial support, and staff (administrative and technical) for attainment of student outcomes and professional development of faculty.

**SPK Platform**

Figure 2 presents a schematic of the SPK platform. In Environment, the Body of Knowledge (BOK) is the complete set of concepts, terms and activities within a professional domain, as defined by the relevant professional association. Strategies for bundling the BOK are integrated into Instructional Methods of the curriculum. As previously described, stakeholders are also an SPK resource. Accreditation and University Requirements are externally derived curriculum content. ABET Criterion 5 and Program Criteria [12] are examples of these requirements.

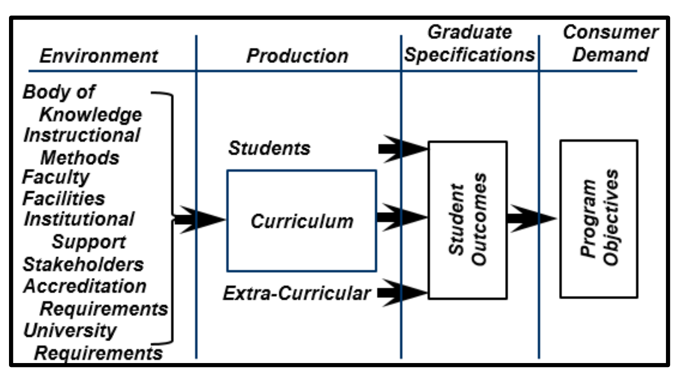



*Figure 2: Academic Program Schematic*

Within the Figure 4 production system, Functional Area Requirements for Students, Curriculum, and Extra-Curricular ensure attainment of Student Outcomes and Program Objectives. Program educational objectives characterize graduates within a few years after graduation and student outcomes describe competencies of students by the time of graduation. An SPK definition for each is:

1. **Program Educational Objectives:** Reflect Consumer Demand for program graduates as well as institutional differences between academic programs.
2. **Student Outcomes:** Describe Graduate Specifications that include ABET outcomes (*a* - *k*) and any other specifications articulated by the program that ensure graduates are able to satisfy consumer demand.

Production System strategies are only a part of a department's larger resource allocation strategy. There are synergistic opportunities for academic programs and faculty scholarship and service. There are also times when these activities compete for departmental resources. Scorecard metrics for department as well as the academic program activities are tools for broad-based resource allocation strategies.

***Figure 3: Shewart Cycle***

Activity-Based Management (ABM) [13] is a systemic approach to continuous improvement in functional area metrics by improving efficiency (eliminating non-value activities). An increase in efficiency is an improvement in (or constant) a functional area metric with the same (or less) resources. Other scorecards monitor production system effectiveness (measure attainment levels of student outcomes and program objectives). Academic program accountability requires appropriate metrics and methods to monitor program stability, efficiency and effectiveness. Accountability is then embedded in quantitative and qualitative analysis tools for administering the SPK. Crowdsourcing engages stakeholders and their domain knowledge in ABM activities.

Shewart's **P**lan, **D**o, **C**heck, and **A**ct (PDCA) Cycle [14] in Figure 3 is an organizational tool for continuous improvement. A brief description is as follows:

- **PLAN:** Identify processes, resources, and develop an implementation plan to improve scorecard metrics.
- **DO:** Implement the plan, allocate resources, modify processes, and collect scorecard metrics and related data.
- **CHECK:** Compare actual scorecard metrics with expected results. Identify deviations from expectations, causes of the deviations, and their effects on the implementation plan. (Time series data may help identify trends in metrics over several PDCA cycles.)
- **ACT:** When implementation results are a cost effective improvement in metrics, production system modifications and resource allocations become the new standard. Otherwise, the previously developed activities remain. When comparison results are not consistent (better or worse) with expectations, there is insufficient knowledge about the production system and additional analysis and possibly PDCA cycles are needed.

**SPK Environment**

The importance of the PDCA is based on the following Deming's Principles [15].

1 Constancy of purpose towards improvements in the production system (program stability and efficiency) and student outcomes, and program objectives (effectiveness).

2 Cease dependence on inspecting by focusing on statistical evidence of quality within production system activities (monitor processes not students).

3 Utilize analytical and creative thinking to maintain stability, and improve program efficiency and effectiveness. Lack of efficiency and/or effectiveness are often the result of poorly designed processes.

4 Decisions must be based on objective data, not personal or situational thinking.

The proposed SPK also satisfies the following ABET General Criterion 4:

*The program must regularly use appropriately documented process for assessing and evaluating the extent to which student outcomes are being attained. The results of these evaluations must be systematically utilized as input for the continuous improvement of the program. Other available information may be used to assist in the continuous improvement of the program.*

In contrast to traditional descriptive statistics for institutional assessment, the SPK is a paradigm shift to inferential statistical methods for developing predictor relationships between Students, Curriculum, and Extra-Curricular activities and their effects on student outcomes and program objectives. To avoid randomness in the data as the basis for changes in the degree program, scorecard metrics for program stability and efficiency must distinguish "special cause" and "random" (or noisy) fluctuations. Without timely access to metrics data, there is the potential for program changes to affect improvements in metrics for an environment that no longer exists.

The 2008 ABET accreditation visit of the industrial engineering degree program at Tennessee Tech was based on a similar SPK that consisted of a network of Excel workbooks residing on a SharePoint platform accessible via the Internet. Limitations of the original SPK were a tight coupling of course outcomes to student outcomes and limited capability for analyzing student outcomes and program objectives. However, the department received critical acclaim from the ABET visiting team for Criterion 4 innovation and the approach was recommended for consideration by the entire college. Departmental faculty consensus was the SPK required less effort than the traditional approaches to ABET and enabled faculty to devote more time to other responsibilities. After receiving accreditation, the degree program was terminated and discussions on administering other degree programs in a similar manner never occurred.

## III. Program Efficiency

### Overview

For an efficient academic program, all production system are stable and all non-value added activities are eliminated. This section focuses on the curriculum efficiency. However, a similar analysis is necessary for Extra-Curricular and Students functional areas.

Developing closed form relationships for time-variant course outcome dependencies is intractable because of the complexity of collecting meaningful data. For example, twenty courses with an average of five outcomes per course produces 100 course outcomes. Multiple course instructors exacerbate the problem. Because allocation of faculty, facilities, and institutional support resources typically lag vaguely defined curriculum requirements, historical data on changes in course outcomes resulting from program changes is seldom available. To compensate for the lack of historical data, an SPK relies on domain knowledge of stakeholders to assist with validating the curriculum.

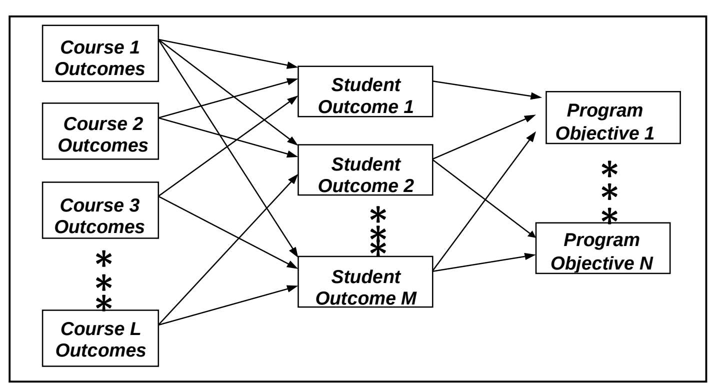



***Figure 4: Course Outcomes – Program Objectives Map***

As indicated in Figure 4, a curriculum is bundled into courses with associated Course Outcomes (Course Learning Outcomes). The suggested Curriculum design incorporates concepts and tools from Cognitive Mapping [16], Fuzzy Logic [17], and Bloom's taxonomy [18]. Course outcome metrics for efficiency are derived from the dependency:

***Course Outcomes =f(Students, BOK Methods, Faculty, Facilities, Institutional Support)***

The definition of Students includes recommending academic options to students that more closely match their capability and interests. The dependency relationship for students is*:*

***Students = f(Advising methods, Faculty, Facilities, Institutional Support)***

BOK Methods in course outcomes are associated policies and procedures for developing course content and related outcomes. Bloom Taxonomy levels of ability to characterize course outcomes are as follows:

1. **Knowledge** is a starting point that includes both the acquisition of information and the ability to recall information when needed.
2. **Comprehension** is the basic level of understanding. It involves the ability to know what is being communicated in order to make use of the information.
3. **Application** is the ability to use a learned skill in a new situation.
4. **Analysis** is the ability to break content into components in order to identify parts, see relationships among them, and recognize organizational principles.
5. **Synthesis** is the ability to combine existing elements in order to create something original.
6. **Evaluation** is the ability to make a value judgment using a standard.

Techniques to assess learning are well-documented. For example, modern psychometric methods, such as item-response theory (IRT) models for determining students' expected vs. observed performance are techniques to assess learning [19]. Rasch models are used to analyze assessment data to measure abilities, attitudes, and personality traits. Establishing consistency between course outcomes and BOK topics within the course, as well as eliminating course duplication are among strategies for improving curriculum efficiency. New learning pedagogies are incorporated into the curriculum only after improvements in course outcomes are validated by a PDCA analysis.

**Analysis of Program Efficiency**

An analysis of variability in course outcome metrics determines when a change in the course produces a substantive change in the course outcome metric. The assumption is 85% of students completing a course demonstrate competency (grade of C or above) on each course outcome. Less than 85% indicates an unstable course (course entropy) caused by poorly designed course or student scheduling issues (not prepared for the course). Several courses violating the 85% heuristic indicate curriculum stability issues since a student's performance in a course affects their performance in downstream courses.

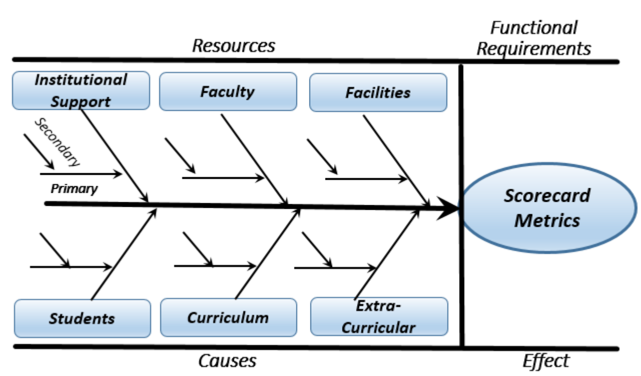



***Figure 5: Fishbone Diagram for Process Improvement***

The Ishikawa (Fishbone) Diagram [20] in Figure 5 is a cause-and-effect analysis tool for performing root cause analysis of an unstable course or curriculum. The diagram summarizes systems knowledge and the effects of the environment on course outcome metrics. Primary and Secondary Causes are impediments to student competency in course outcomes. Fishbone diagrams are also a tool for administering continuous improvement (PDCA analysis) in courses and/or curriculum.

Sample scorecards in Figure 6 monitor average course outcome score (**α**) over a six-year program accreditation cycle. A reasonable assumption is Grade of C (2.0) or above is an acceptable outcome. Therefore, only students with a C or above are included in the metric. For strategic reasons, the target score of 3.0 ensures competent students maintain scholarship eligibility. A course grades scorecard is also maintained to compare course outcome results with the course grade.

The range metric monitors variability (**β**) in percentage of students who made a *C* or above. The target metric is 85%. Within a stable curriculum, these scorecards enable faculty to identify at-risk students. Although not a rigorous statistical approach, Western Electric Rules [21] may be used as guidelines to detect out-of-control (non-random conditions) course outcomes that indicate an unstable course. These scorecards are, in effect, a Kanban, queue limiter, in the sense that sources of delays and/or blockages of students moving through the academic program are easily detected. [22].

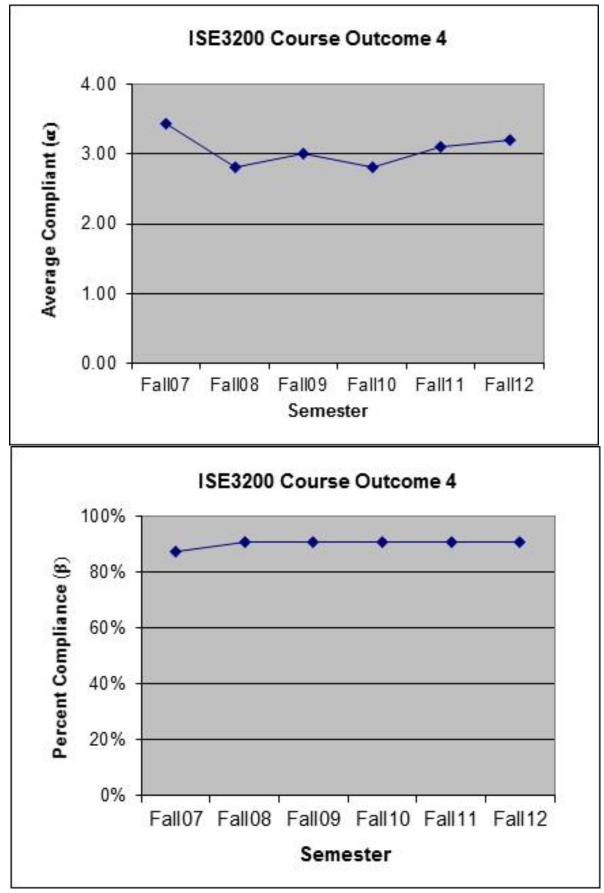


***Figure 6: Course Outcome Scorecard***

In an Excel course workbook for each course is a compendium of course specifications. Contents include an ABET course syllabus, course outcomes descriptions shown in Figure 7, and scorecards for each course outcome. Also included are time ordered details of course changes and rationale for the changes.

Course monitoring material also includes maintaining PDF samples of student performance on course outcome metrics. Because all ABET program accreditation material is internet accessible, peer review is an option for internal and external validation of the degree program. A student survey is an option for validating course delivery attributes that include class environment (e.g. class size, facilities, etc.) and course management (e.g. class organization, focused lectures, engaging students, etc.).

| % Course | # | Course Outcome | Level | a | e | f | g | i | k | l | m | n | Metrics |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30% | 1 | **Formulate basic optimization models for production systems** including. continuous and discrete decision variables, system constraints and objective functions using linear programming. | 5 | 5 | 20 | | 5 | 5 | 20 | 10 | 20 | 15 | Exam I |
| 20% | 2 | **Solve basic optimization models using Simplex Algorithm and Excel Solver.** feasible solution spaces, basic solutions, alternative optimal solutions | 3 | 20 | 20 | | | 5 | 20 | | 20 | 15 | Exam II and Class Project |
| 30% | 3 | **Perform sensitivity analysis using mathematical models.** Use duality and graphical solutions to assess changes in cost coefficients, resource availability, additional decision variables and constraints, and resource consumption rates. | 6 | 20 | 20 | | | 5 | 20 | | 20 | 15 | Exam III |
| 20% | 4 | **Formulate and solve basic optimization models for production systems** using network algorithms. | 5 | 5 | 20 | | | 5 | 20 | 10 | 20 | 20 | Exam IV |

***Figure 7: ISE 3400 Course Outcome Description***

The number of Figure 6 scorecards (course outcomes) shown are indicated in Figure 7. For example, ISE 3400 has four course outcomes. Because these charts are updated throughout the semester, the lapsed time to prepare an end-of-semester summary report of average and percent compliance for each course outcome is a week after the semester ends. This enables a review of curriculum metrics at the end of each semester. For a course outcomes analysis, the course workbook is accessible via the hyperlink in column 1 of Figure 8. Stable course outcomes are a essential for an analysis of degree program effectiveness and efficiency.

| Course | Course Outcome | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | |
| | α | β | α | β | α | β | α | β | α | β | α | β |
| ISE2000 | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | | |
| ISE3200 | 3.0 | 82% | 3.0 | 64% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% |
| ISE3220 | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | | | | |
| ISE3310 | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | | | | |
| ISE3400 | 2.7 | 58% | 2.5 | 44% | 3.0 | 100% | 3.0 | 100% | | | | |
| ISE3410 | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% |
| ISE3800 | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | | | | | | |
| ISE3900 | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | | |
| ISE4230 | 2.8 | 94% | 3.1 | 94% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | | |
| ISE4240 | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | | | | | | |
| ISE4400 | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | | | | | | |
| ISE4410 | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | | | | | | |
| ISE4500 | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | | |
| ISE4510 | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | | | | | | |
| ISE4600 | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% |
| ISE4650 | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | 3.0 | 100% | | |

***Figure 8: Course Outcomes Summary by Course***

## IV. Program Effectiveness

### Overview

Program effectiveness is an assessment of attainment levels for student outcomes and program objectives. As in the discussion on program efficiency, this section focus is on the curriculum and specifically using quantified course outcomes to develop quantitative measures of student outcomes and program objectives. Quantifying student outcomes is based on the dependency:

***Student Outcomes = f (Production System)=f(Students, Curriculum, Extra-Curricular)***

Course outcomes links in Figure 4 are the basis for quantifying the curriculum emphasis on student outcomes. The 4-tuple of parameters for a course outcome are:

1) Percent of the course allocated to the course outcome (0 – 100).
2) Course credit hours.
3) Bloom Taxonomy Index (1 - 6).
4) Relevance of course outcome to student outcome (0 – 1.0).

The Fuzzy Logic parameter measures the importance (degree of association) of a course outcome to a student outcomes (*a* - *n*). Figure 7 presents workbook contents with values for each course outcome parameter (credit-hours not shown). Columns a - n are the degrees of association. To eliminate double counting of course content, degrees of association sum to 1.0.

The 4-tuple products form a Student Outcome Contribution vector and each term represents Course outcome contribution to a student outcome. The sum of student outcome contributions over all course outcomes is the cumulative emphasis of the curriculum on that student outcome (Graduate Specifications). The summation over each cumulative student outcome is:

$$CumulativeStudentOutcome(k) =$$

$$\sum_{i}^{M} CourseCredits(i) * \sum_{j=1}^{M} \begin{Bmatrix} PortionCourse(i) \\ Allocated\ to \\ CourseOutcome(j) \end{Bmatrix} * \begin{Bmatrix} Bloom \\ Taxonomy \\ Index(i,j) \end{Bmatrix} * \begin{Bmatrix} CourseOutcome(i,j) \\ StudentOutcome(k) \\ Association \end{Bmatrix}, \forall\ k = 1, \ldots O$$

Where N is number of courses, M is number of course outcomes for a course, and O is the number of student outcomes. These values, shown in Figure 9, provide insight into the relative importance of student outcomes in the program and are essentially quantified specifications on abilities of graduates. An analysis of student outcomes reconciles relative emphasis of the program, as indicated by cumulative student outcomes, with actual student activities demonstrating student abilities.

| Outcome | Student Outcome Description | CSO* |
|---|---|---|
| k | *ability to use the techniques, skills, and modern engineering tools necessary for the engineering practice* | 27.346 |
| e | *ability to identify, formulate, and solve engineering problems* | 24.195 |
| b | *ability to design and conduct experiments as well as to analyze and interpret data* | 18.809 |
| a | *ability to apply knowledge of math, engineering, and science* | 16.802 |
| n | *ability to utilize analytical techniques for decision-making* | 14.075 |
| m | *ability to develop and evaluate abstract models of system performance.* | 13.638 |
| c | *ability to design a system, component or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainablity* | 11.932 |
| l | *ability to specify data requirements to assess and improve system performance* | 11.302 |
| g | *ability to communicate effectively* | 10.247 |
| o | *ability to provide leadership in individual and team situations* | 5.759 |
| d | *ability to function on multi-disciplinary teams* | 4.363 |
| i | *recognition of the need for, and an ability to engage in life-long learning* | 3.456 |
| h | *the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context* | 2.203 |
| f | *understanding of professional and ethical responsibility* | 1.718 |
| j | *knowledge of contemporary issues* | 0.090 |
| ***Cumulative Student Outcome** | | |

***Figure 9: Sorted Cumulative Student Outcomes***

Ranking of course outcome contributions to student outcomes in the last column in Figure 10 provides insight on importance of a course outcome to a student outcome. Also in Figure 10 is the rank order of cumulative student outcome indicating relative degree program emphasis on a student outcome.

| Course Number | Outcome | Outcome Description | Course Credits | Bloom Index | Portion of Course | Degree of Association | Contribution to Outcome |
|---|---|---|---|---|---|---|---|
| ISE4000 | 1 | Understand, explain, and demonstrate the steps necessary for planning and managing a successful technical project. | 3 | 6 | 60% | 50 | 5.400 |
| ISE3310 | 3 | Design and evaluate jobs, workstations, tools, and systems with respect to work content and physical and cognitive ergonomics. | 4 | 6 | 25% | 40 | 2.400 |
| ISE3400 | 3 | Perform sensitivity analysis using mathematical models. Use duality and graphical solutions to assess changes in cost coefficients, resource availability, additional decision variables and constraints, and resource consumption rates. | 3 | 6 | 30% | 20 | 1.080 |

***Figure 10: Sample Course Outcome Contribution to Student Outcome* (a)**

Program objectives (consumer demand) validate quantified student outcomes as a platform for successful careers. Quantified program objectives is based on the dependency:

***Program Objectives = f (Student Outcomes) = f (Production System)***

Quantified student outcome links in Figure 6 are the basis for quantifying student outcome contributions to program objectives. The 2-tuple of parameters for each student outcome are Cumulative Student Outcome Contribution and relevance of the outcome to a program objective (0 – 1.0). In this instance, program outcome relevance is specified by external stakeholders. The 2-tuple products form a Program Objectives Contribution vector and each term represents the student outcome contribution to an objective. The summation over each program objective is:

$$CumulativeProgramOjbective(l) =$$

$$\sum_{k=1}^{O} \{CumultiveStudentOutcome(i)\} * \left\{ \begin{matrix} StudentOutcome(k) \\ ProgramOjbective(l) \\ Association \end{matrix} \right\} \;, \forall\, l = 1, \ldots P$$

Where P is number of program outcomes. Program emphasis by program objective is presented in Figure 11. Cumulative program objectives are quantitative measures of career expectations which are compared with consumer demand for graduates. Similar to the analysis of student outcomes, an analysis of program objectives reconciles relative emphasis of the program with early career activities of program graduates. A reasonable review cycle is two years for student outcomes and three years for program objectives. However, depending on the volatility of the program environment (e.g. faculty turnover, dramatic changes to the academic profile of students, changes in demand for graduates, etc.), the review cycle may be shortened.

| # | Program Objective Description | CPO* |
|---|---|---|
| 1 | *Lead the planning, designing, developing, and controlling of integrated systems.* | 33.971 |
| 2 | *Apply concepts and tools to improve processes in service and manufacturing systems.* | 34.943 |
| 3 | *Model complex systems and make inferences for effective decisions.* | 35.898 |
| 4 | *Pursue graduate education in either a research or professional degree program.* | 37.131 |

*** Cumulative Program Objective***

***Figure 11: Cumulative Program Objectives***

**Analysis of Program Effectiveness**

An opportunity to address previously identified industrial engineering program SPK limitations on assessment of program effectiveness occurred while teaching the computer science course *Professionalism, Communication, and Research in Computing*. Bloom's Taxonomy was extended from student outcomes to program objectives. A requirement for students to develop a portfolio on *WIX.com* as a platform for career planning, and monitoring student outcomes and program objectives by stakeholders was added to the course. The *WIX.com* platform of portfolios is the prototype to demonstrate capability of collecting data for analysis of student outcomes and program objectives.

Portfolio categories are *Education, Honors and Awards, Academic Experience, Work Experience, Core Values*, and *Resume*. Academic and work experience are based on Bloom's Taxonomy to characterize student activities. Curriculum and Extra-Curricular activities chronologically map to student outcomes in Academic Experience. Cooperative education and internships activities map to Work Experience. The resume is a summary of relevant information derived from other portfolio sections to support the resume's employment objective. In contrast to a view of students through the lens of subject matter standardized exams, Academic Experience and Work Experience provide a holistic view of current students as well as program graduates. To formalize the assessment effort, an information system is needed to organize, retrieve, and summarize sets of portfolios.

A sample Academic Experience section is presented in Table 2. Through the sophomore year, students have difficulty populating academic experience categories because they are beginning to enroll in BOK courses. In the 3$^{rd}$ year, the portfolio is an important tool for students to focus on electives that match career aspirations.

An expanded role of academic advising includes assisting students with populating the portfolio from previous semester's coursework and advising on student outcomes strategies to ensure academic experience reflect career aspirations. A portfolio also enables a student to share an in-depth perspective on strengths in the context of career aspirations with prospective employers.

An analysis of student outcomes effectiveness is based on Academic Experience, and the basis for program objectives analysis is Work Experience. The commitment to lifelong learning is reflected in Academic Experience. A majority of students enrolled in the course indicated they would voluntarily maintain the portfolio after graduation to assist with assessment of program effectiveness.

## V. Conclusions

Although there are similarities, regional engineering programs are very different from programs in a flagship institutions. Assuming flagship strategies are easily transferrable to regional universities is problematic. The primary difference is an engineering curriculum that satisfies ABET General criteria and meets academic needs of students from diverse and time variant student profiles in a regional university creates uniquely challenging problems.

Another difference between regional and flagship institutions is the extent alternative strategies are applied to creating and administering institutional revenue streams. Variations in results of these strategies create small perturbations in flagship institution degree programs but may adversely affect stability of academic programs in regional universities. Insufficient resources in regional universities are major constraints for quickly adapting strategies to support suddenly unstable academic programs caused by leveraging. While leveraging strategies are not de facto problematic, regional university academic programs are much more sensitive to the trade-offs of leveraging. Acknowledging these institutional differences is essential for developing strategies to ensure degree program accountability.

This paper proposes an organizational platform and related tools to administer accountability for an ABET accreditation program based on Deming's System of Profound Knowledge (SPK). Functional area systems of the SPK are derived from the decomposition and reconfiguration of the ABET General Criteria. Program accountability is broadly defined as constant emphasis on maintaining a stable degree program (majority of enrolling students successfully complete the program); reducing non-value added activities consuming academic program resources (program efficiency); achieving quantified student outcomes and program objectives (program effectiveness); and assisting at-risk students by minimizing academic program discontinuities and advising on alternative academic strategies that match their interests and needs. . These concepts are easily extendable to science, technology, engineering, and mathematics (STEM) programs.

| Table 2: Academic Experience - 1st Semester, Junior - Computer Science |
|---|
| ***(a) An ability to apply knowledge of computing and mathematics appropriate to the program's student outcomes and to the discipline.*** <br> **Fall 2015: International Collegiate Programming Competition** <br> Solved and programmed mathematical solutions for various programming challenges <br> ***(b) An ability to analyze a problem, and identify and define the computing requirements appropriate to its solution.*** <br> **Fall 2016: CSC 2500 Design of Algorithms** <br> Analyzed the time and space complexity of various algorithms <br> ***(c) An ability to design, implement, and evaluate a computer-based system, process, component, or program to meet desired needs.*** <br> **Fall 2016: Malware Research Group** <br> Developed a malware testbed to perform static and dynamic analysis on malware samples inside a sandbox <br> **Spring 2016: CSC 2120 Objected Oriented Programming** <br> Designed and developed a pizza ordering system <br> ***(d) An ability to function effectively on teams to accomplish a common goal.*** <br> **2015: Current: LiquidEarth** <br> Designed, developed, and validated a flood prediction application In a team environment <br> ***(e) An understanding of professional, ethical, legal, security and social issues and responsibilities.*** <br> ***(f) An ability to communicate effectively with a range of audiences.*** <br> **Spring 2016: PC 2500 Professional Communications Honors** <br> Presented to large groups in various professional settings <br> ***(g) An ability to analyze the local and global impact of computing on individuals, organizations, and society.*** <br> **Spring 2016: Women in CyberSecurity Conference** <br> Conference volunteer <br> ***(h) Recognition of the need for and an ability to engage in continuing professional development.*** <br> **Spring 2016: Rising Renaissance Engineer Spectrum Award for Computer Science** <br> ***(i) An ability to use current techniques, skills, and tools necessary for computing practice.*** <br> ***(j) An ability to apply mathematical foundations, algorithmic principles, and computer science theory in the modeling and design of computer-based systems in a way that demonstrates comprehension of the tradeoffs involved in design choices.*** <br> **Summer 2016: Auburn HPC Research Internship** <br> Researched and implemented a poly-algorithm for distributed matrix multiplication with a pluggable object oriented software architecture <br> **Fall 2016: ConCUDA Concurrent GPU Kernel Research** <br> Researching on concurrent GPU kernels, optimizing BLAS routines and building cross platform GPU applications <br> ***(k) An ability to apply design and development principles in the construction of software systems of varying complexity.*** <br> **Summer 2016: Auburn HPC Research Internship** <br> Implemented an object-oriented cross-platform matrix multiplication framework in a traditionally procedural domain |

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