Using Statistical Process Control to Enhance Student Progression

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ABSTRACT

Public interest in educational outcomes has markedly increased in the most recent decade; however, quality management and statistical process control have not deeply penetrated the management of academic institutions. This paper presents results of an attempt to use Statistical Process Control (SPC) to identify a key impediment to continuous improvement in the academic setting and to facilitate continual improvement of instructional performance. An illustration from an undergraduate degree program in business administration is provided.

INTRODUCTION

During the 1990s Total Quality Management (TQM) was a hot topic among American business professionals. Companies adopted TQM, in many cases with a great deal of passion. Adherents promoted widespread adoption – not just in industry but also in the public sector. Universities and university systems were not only encouraged to adopt quality management by external stakeholders such as boards of trustees and advisory councils, but also pursued the approach because they had funding concerns and a need to "do more with less". AACSB International, a premier worldwide accrediting organization for colleges of business, convened a major conference of business school and industry leaders to facilitate adoption of quality management practices in business. Among the recommendations of that convention were the following points on improving the teaching/learning process:

- "rather than obtaining feedback from students in the form of course critiques at the end of the course, institute feedback throughout the course.
- apply statistical methods to detect the presence or absence of 'out of control' conditions in the education system.
- as role models, faculty should practice TQ in the conduct of courses, performance of research and interactions with students, staff, and colleagues.
- the university should become a model of a TQ focused organization; in so doing, students' expectations will become the expectations of their employers..." (Gitlow, et al., p. 6, 1994)

With these, and other, recommendations in hand, AACSB funded the development of a 231 page curriculum resource guide for quality management. Similarly, in the last decade various studies have discussed the application of quality management principles to higher education (e.g., Baile and Bennett, 1996; Ensby and Mahmoodi, 1997; Mehrez et al., 1997; Vazzana et al., 1997; Willis and Taylor, 1999). However, although assessing educational processes is necessary for continual improvement of educational outcomes, institutions of higher learning seem to stand in need of examples demonstrating actual application of quality methods in their environment and greater expertise in the techniques to perform such assessment. For example, Lawrence, et al. (2008, p. 453) seeks to "stimulate thinking about the application of a proven quality management methodology to academic settings where formal improvement programs such as six sigma are not commonly found."

W. Edwards Deming, a leading proponent of quality management and the practice of continuous improvement, promoted an improvement cycle known variously as the Shewhart cycle, Deming cycle, PDCA (Plan-Do-Check-Act) Cycle, or PDSA (Plan-Do-Study-Act) cycle (Evans and Lindsay, 2002). Like TQM, this approach has been widely used in industry, however has not deeply penetrated the administration of instruction in American universities (Mergen et al., 2000). While there is great interest in improvement and innovation, continuity of effort seems to be lacking. It is at least possible that this continuous improvement practice has not penetrated academic administration because of a lack of awareness of the way in which statistical control of processes can be used to establish an understanding of the range of outcomes one might expect under normal circumstances and a baseline for ongoing improvement. Conversely, statistical control may not be widely applied in academic administration because continuous improvement – in a form such as the P-D-S-A cycle is not practiced. Regardless, statistical process control is ideal for capturing educational processes such as retention-progression-graduation, because it focuses not only on measuring outcomes, but also, and importantly, on measuring processes, and on prevention of nonconformance rather than ex post detection. (Montgomery, 2000).

More recently, improvement efforts at universities have come in the form of enrollment management efforts directed toward student retention, progression and graduation (RPG). These efforts are becoming increasingly important as our society is becoming more and more efficiency and value conscious. As student cohorts progress from the freshmen to senior level, some individuals are lost due to attrition. While there may be many factors that play a role in student attrition, including student characteristics and institutional practices, attrition does cause reduced efficiency and lost opportunities in the educational system. As such, RPG represents a significant family of performance measures for universities today, and will likely continue to grow in importance.

Retention, Progression and Graduation are terms that have been operationally defined by the Integrated Postsecondary Educational Data System (IPEDS). Specifically, a first time freshman is a degree-seeking undergraduate who enters college for the first time in the fall term or who has graduated from high school within the same calendar year of that fall term. Cohorts are groups of first time, full time, degree-seeking freshmen who enter a specific university during a given fall term. A university's retention rate for a given cohort is defined as the percentage of that group that returns to the same institution the following fall. Many universities focus primarily on freshman retention, meaning this statistic is not always tracked as the cohort matures into their third year and beyond. Progression, however, is monitored throughout the academic career of the cohort. Progression is defined as the fall cohort who progress to the next classification by the subsequent fall. The rate of progression for a cohort in a given fall would be reflected in a histogram presenting the percentage of students in each classification. Graduation rates are defined as the percentage of a fall cohort that graduates by the summer of their sixth year. While the above describes an entry cohort based methodology, Lee and Buckthorpe (2008) present an exit cohort method. For study programs in a more-or-less steady state operational situation, their method has the benefit of providing a current indicator of the current state of affairs in a course of study, rather than requiring a lag of several years while an entry cohort progresses. In addition, it has been tested over several years and "has proved to be a robust method" of calculating non-completion rates.

The measurement and use of RPG has recently become quite pervasive among global universities. In the U.S., it is used by the National Collegiate Athletic Association (NCAA) to monitor athletic programs and ensure that universities do not field athletes who are not making academic progress. The consequence of not meeting the NCAA's RPG targets for an athletic team is a reduction in the number of scholarships that may be offered to members of that team. Similarly, university systems around the world have used RPG or non-completion rates as a way of evaluating the relative effectiveness of their member institutions and to establish performance benchmarks. They have also adapted their funding formulas to financially reward institutions that meet RPG targets and penalize those that do not.

In this paper, we present the results of a project that seeks to address the resistance of academic environments to the use of continuous improvement techniques. The project involves developing an illustrative example of Statistical Process Control (SPC) applied to the supervision of instruction. Our example shows that SPC is effective in demonstrating the need for standardization of course outcomes prior to efforts at continuous improvement. It also illustrates the importance of SPC in any improvement cycle that may be used by academic administrators who seek to fulfill the AACSB mandates described above, establish a continual improvement process for the courses they supervise, and/or address demands for improved RPG.

STATISTICAL PROCESS CONTROL

SPC was first proposed by Walter A. Shewhart. In the context of the mass production of parts used by his employer, Shewhart (1931, p. 34) suggested that SPC would lead to at least five favorable outcomes, which he labeled:

1. Reduction in the cost of inspection,
2. Reduction in the cost of rejections,
3. Attainment of maximum benefits from quantity production,
4. Attainment of uniform quality even though inspection test is destructive,
5. Reduction in tolerance limits where quality measurement is indirect.

Shewhart noted that "it is often more economical to throw out defective material at some of the initial stages of production rather than to let it pass on to the final stage where it would likely cause the rejection of a finished unit of product."(Shewhart, 1931, p. 28) Shewhart's perspective, which has now been validated by nearly a century of industrial practice, was that "by eliminating assignable causes of variability, we arrive at a limit to which it is feasible to go in reducing the fraction defective."(Shewhart, 1931, p. 28) Shewhart developed SPC as a method for identifying the assignable causes of variability – those that affect a process at sometimes but not at others - so that they could be removed. The control charting techniques associated with SPC are now widely used in business and other public organizations. However, they are far less prevalent in university administration of instructional processes.

While there are substantial differences between the factories addressed by Shewhart's research in the early 20th century, and universities in the early 21st century, the outcomes envisioned by Shewhart are now being openly promoted in public higher education policy in the United States. In higher education:

1. The call for "reduction in the cost of inspection" is reflected in concerns about the rapid growth in assessment requirements and the cost associated with this growth.
2. The call for "reduction in the cost of rejections" is reflected in efforts by accrediting and funding agencies to assure RPG, or reduce non-completion rates. It is also reflected in the prevalent attempts among undergraduate programs to create "first year experience" programs that demonstrably enhance RPG.
3. The call for "attainment of maximum benefits from quantity production" is re-

flected in the widespread expectation of access to higher education and financial support for the same.

4. The call for "attainment of uniform quality even though inspection test is destructive" is reflected in the fact that the decision to hire a specific graduate cannot be redone. One primary current emphasis of virtually all accrediting agencies seems to be on program assessment. This reflects the need to ensure that instructional processes consistently attain program objectives.
5. The call for "reduction in tolerance limits where quality measurement is indirect" is reflected in the assessment practices of university administrators and in the use of grades, transcripts, and psychometric testing by corporate human resources professional who seek to predict applicant performance in specific types of jobs.

Just as it may be more economical to reject nonconforming parts during early stages of production, so too in higher-education it may be more economical to no longer enroll a student (lacking in aptitude or motivation) at an early stage of their university experience than to allow that student to progress in a program that they are unlikely to successfully complete.

Statistical control charts have been used for many years to monitor the performance of business and manufacturing processes (e.g., Kumar and Gupta, 1993; Harris and Ruth, 1994). A control chart is comprised of a center line, an upper control limit (UCL), and a lower control limit (LCL) and sample values that are plotted against these. The center line is simply the expected value for the statistic being observed. In the U.S., it is common to use "three-sigma" limits – meaning the control limits are three standard deviations away from the mean being observed. The UCL and LCL represent the extent to which one might expect the statistic being observed to vary under normal circumstances. Therefore, observed values outside the control limits are seen as indicators of the presence of some "special cause" acting on the system of interest.

In addition to single points outside of the control limit, the presence of special cause variation may be indicated by patterns of observed values. Examples of such patterns are "two out of three consecutive points more than two standard deviations away from the mean on the same side of the center line", "or four out of five consecutive points more than one standard deviation away from the mean on the same side of the center line", or "a predictable (i.e., seasonal") pattern", or "13 points in a row within one standard deviation of the mean". Hence, to facilitate the use of such "rules of runs", control charts often depict "one-sigma" and "two-sigma" zones in addition to the control limits. These are helpful in interpreting the chart.

In this paper, the specific SPC tool we utilize is the p-chart. These charts are used to monitor the proportion of entities with a specific characteristic in a given sample. To draw p charts, samples are drawn from the population and the proportion of entities exhibiting the characteristic of interest (p) for each sample is calculated. The average proportion ($\bar{p}$) for all samples is calculated using the values from each sample. Given a group of *m* samples, the estimate of the sample average proportion, $\bar{p}$, can be calculated using the formula,

$$\bar{p} = \frac{\sum_{i=1}^{m} p_i}{m}$$

The standard deviation (σ_p), a measure of variation, is used to derive various control limits within which sample proportions are expected to fall. The standard deviation (σ_p) is calculated using the following formula,

$$\sigma_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

Where:

σ_p = Estimate of the standard deviation of the sampling distribution of proportions

$\bar{p}$ = Estimate of the sample average proportion n = sample size

Average proportions and standard deviations calculated in this manner can be used to construct a p-chart in the following manner.

Center line = $\bar{p}$

1 sigma boundaries = $(\bar{p} \pm \sigma_p)$

2 sigma boundaries = $(\bar{p} \pm 2\sigma_p)$

3 sigma limits = $(\bar{p} \pm 3\sigma_p)$

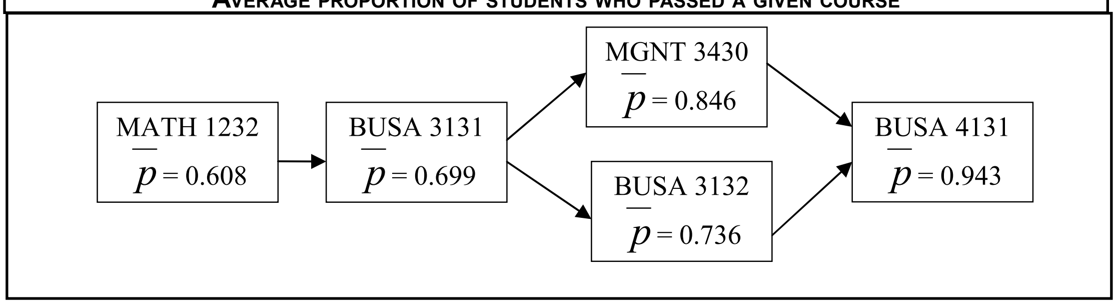
The 3 sigma limits are referred to as the Upper Control Limit (UCL) and Lower Control Limit (LCL). When the sample size is held constant, σ_p will also be a constant and the boundaries and control limits will be straight lines. When the sample size varies, σ_p will also vary, and the recommended approach to handling this situation is to utilize these varying the boundaries and limits. (Duncan, 1986) Sample proportions are plotted on the control chart along with the applicable center line, boundaries, and limits. Depending on the location of plotted values the control chart relative to the boundaries and limits, conclusions regarding the presence of special cause variation can be made utilizing the interpretation rules alluded to above.

APPLYING SPC TO AN ACADEMIC SEQUENCE

Analysis of student academic performance in a sequence of core classes, with the help of statistical control charts, helps explain the impact of instructional factors on retention, progression and graduation. The academic performance of the students enrolled in the undergraduate business degree program of the College of Business Administration at Georgia Southern University between year 2000 and 2008 was studied and analyzed for this purpose. Data for students enrolled in summer classes, web courses and other satellite campuses was eliminated to remove unique populations that could skew the results. The results for the universe of students enrolled during this period were used to determine the average proportion ($\bar{p}$) of students progressing. The proportion (p) progressing in a given semester, and the appropriate control limits for that semester were determined using the results for all of that term's enrollees. Hence, our control limits vary by semester.

The effort focused on academic performance of students in five courses, which all business students are required to complete. These are taken in sequence between the second and final semester of the undergraduate business degree program. These courses are also generally understood to be the sequence (or critical path) that is most likely to impact a student's time to graduation. Thus, this project focused on explaining progression and graduation related instructional issues – particularly, we needed to discover if special causes of variation in pass rates can be identified and investigated using SPC. Since a letter grade of "C" or better is required for a business student to pass in each of these courses, the proportion of students achieving a grade of "C" or better was calculated for each of the five courses during spring and fall semesters for the time period between spring 2000 and spring 2008. P-charts from the data analysis for five courses under consideration are shown in Figures 2 through 6. From Spring, 2000 through Spring, 2008 these courses demonstrated substantial variation in the average proportion of students achieving a grade of "C" or better (Figure 1).

Figure 1
Average proportion of students who passed a given course



MATH 1232

Math 1232 is a Survey of Calculus course and it is the first class in the critical sequence. Two things are obvious from the control chart (Figure 2); first there is an overall upward trend in the proportion of students passing the class and second there is a wide range in the semester proportions observed. These run from 0.496 to 0.735 with a mean proportion of 0.608. The department chair suggests "the spring results are better because most of the students take College Algebra in the fall and then Survey in the spring. Fall semesters probably involve off-semester students who failed previously and transfer students." One possible cause for the upward trend includes an increase in admissions standards. It is also possible that the higher rates recently observed are a result of greater university attention to the first year experience, and/or improved coordination and staffing of the class. It appears that the improvement in pass rates does not simply reflect a relaxation of standards in this course, because this could lead to lower pass rates in subsequent courses. There are three points of specific concern on this control chart. In fall 2002, the proportion of students passing the course was significantly lower than mean value ($\bar{p}$). Similarly the proportion of students passing the course is significantly higher than upper control limit (UCL) in spring 2007. The proportion of students passing the course is slightly higher than the upper control limit in Spring 2008. Investigations of reasons for poor student performance in Fall 2002 may give us insight into what does not work in MATH 1232, whereas investigations of assignable causes for improved student performance in the Spring of 2007 and 2008 may help us identify what does work particularly well and could be institutionalized to improve student progression by improving pass rates in this course in future semesters.

BUSA 3131

BUSA 3131, the second class in the critical sequence, is a Business Statistics course. This chart (see Figure 3) has a mean proportion ($\bar{p}$) of 0.699 and the proportion (p) for given semesters ranges from 0.589 to 0.782. There is a significant

FIGURE 2

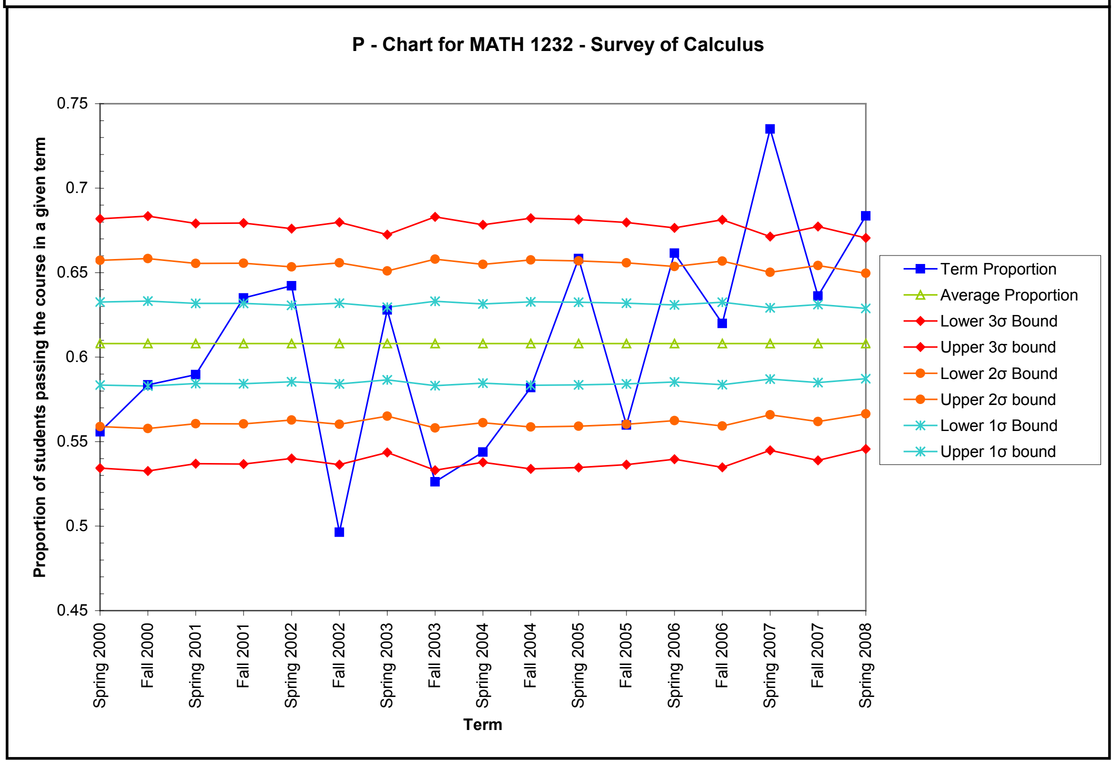
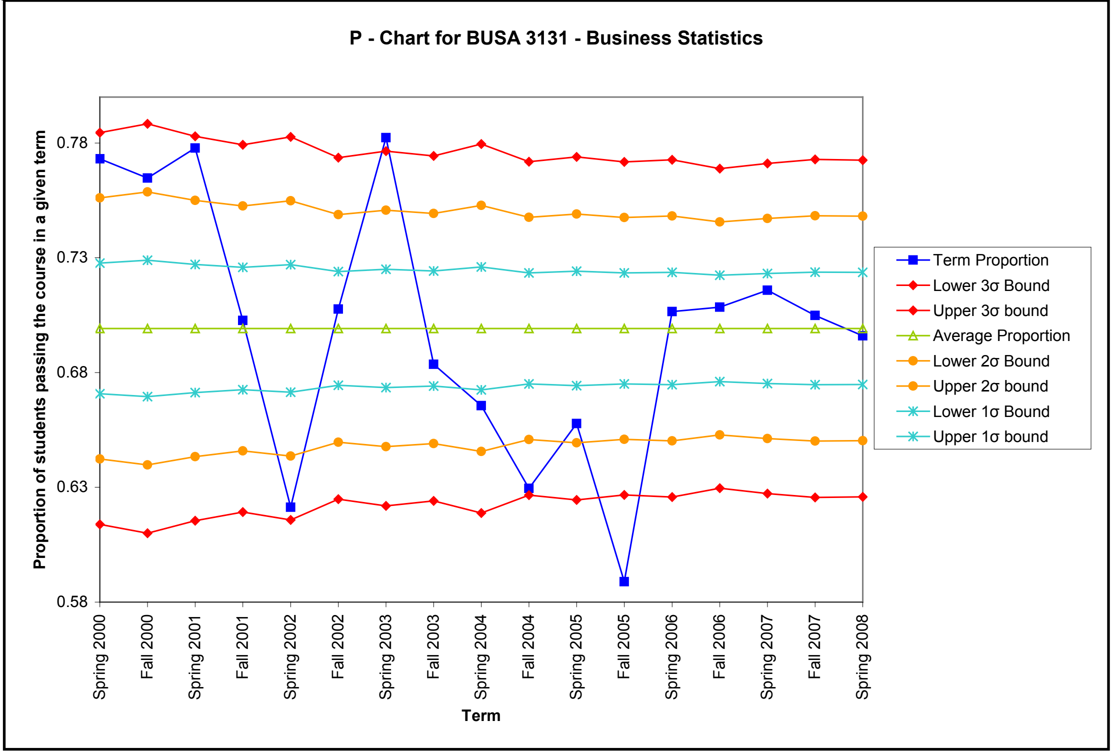


FIGURE 3

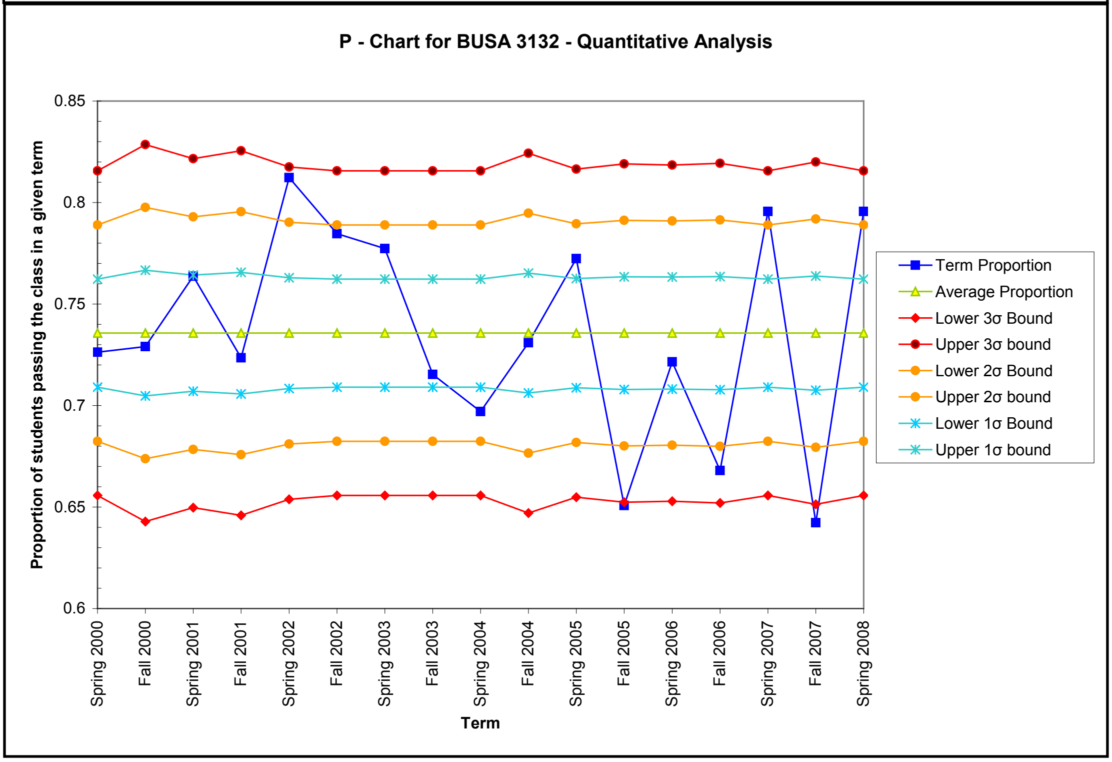


variation in proportion (p) from Spring 2001 to Spring 2006 indicating presence of some assignable causes and a lack of control over student performance in this course over this given period, whereas the proportion has been less variable (staying close to the center line) after Spring 2006. This reduction in variation most likely reflects a change in the staffing approach used in the course. Due to a reorganization of the departmental structure of the college, this course has been administered in two different departments and by four different department chairs over the period charted. Prior to 2003 the department was prone to a heavy reliance on temporary and adjunct faculty and had substantial turnover of tenure-track faculty. The resulting wide variations in semester pass rates reflect the lack of continuity among instructors. Upon re-alignment of departments in the fall of 2003, the new supervisor for this course relied on a mix of faculty from economics and quantitative methods. Finally, beginning in the fall of 2005, a third department chair consolidated staffing of the course with quantitative methods faculty and this practice has since continued. While there are points outside of the limits on this chart – the pattern simply reflects the impact of organizational dynamics and staffing policies. It suggests the importance of remaining with the current approach to staffing the course. It should be noted that it is far easier to adjust the rigor of the class - and the consequent pass rates – than to reduce the variation in pass rates. Hence, the accomplishment of the department chair who introduced the staffing model currently used is very significant, both for this course and for staffing of other courses. Based on the fact that virtually all doctorally qualified faculty in business disciplines have received adequate training in basic business statistics, many would argue against a requirement that quantitative analysis faculty be used exclusively to staff the core service course in statistics. However, it is clear from our experience, and this control chart, that unifying the instructional corps with this requirement has beneficially reduced variation in the proportion of students passing this class.

BUSA 3132

BUSA 3132 is called Quantitative Analysis, and covers topics such as forecasting, queuing, deci-

FIGURE 4



sion analysis and linear programming. BUSA 3131 is a prerequisite to BUSA 3132. As the p-chart for BUSA 3132 shows (Figure 4), there is obvious variability from semester to semester with only one semester where the proportion (p) is outside the lower control limit. The proportion (p) of students who pass this course ranges from a low value of 0.642 to a high of 0.812, with a mean proportion ($\bar{p}$) of 0.736. In addition to an out of control point for fall 2007 of 0.642, this chart exhibits an interesting pattern following the fall of 2004. Namely, the proportions for Spring semesters are consistently higher than the proportions for Fall semesters. This could reflect either a staffing pattern or a different mix of students in the spring (with more second attempters). Indeed, given that two new tenure-track faculty members were added to the staffing of this class in the fall of 2004, it seems likely that staffing plays a role in the observed pattern.

MGNT 3430

MGNT 3430 is an operations management course for undergraduate business majors. It can be seen from the control chart (Figure 5) that semester averages of the passing proportion range from 0.785 to 0.913 with an overall average of 0.846. The proportion of students passing the class falls within the control limits for each semester. The staff teaching this course has been active with one another in a "teaching circle." It is possible that the ongoing and consistent interaction among this instructional cadre is a primary factor in the observed degree of control over student pass rates.

BUSA 4131

BUSA 4131, Strategic Management, is the last course in the sequence. Semester proportions of passing students in this course range from a minimum value of 0.883 to a maximum value of 0.981 with a mean of 0.943 (Figure 6). The proportion, 0.883, for fall 2000 is outside the lower control limit of 0.889 for that semester. Given that this is eight years prior to the construction of the control chart, and all of the faculty who taught the course in that semester are no longer affiliated with the university, it is difficult to determine the cause of this point. Three possibili-

FIGURE 5

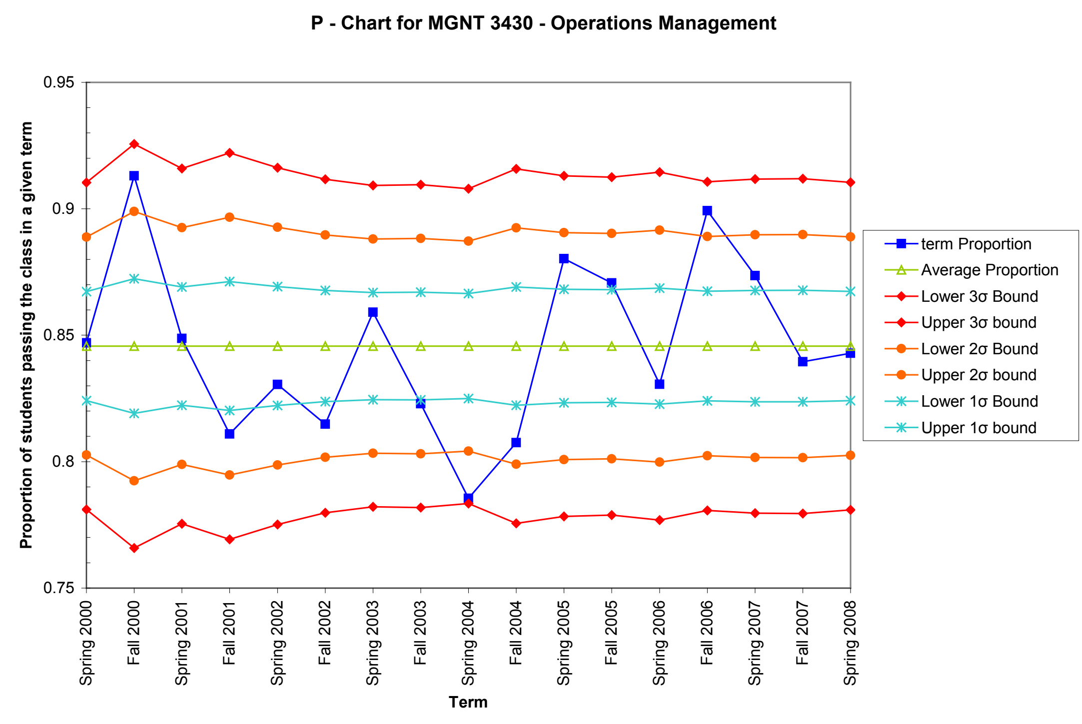
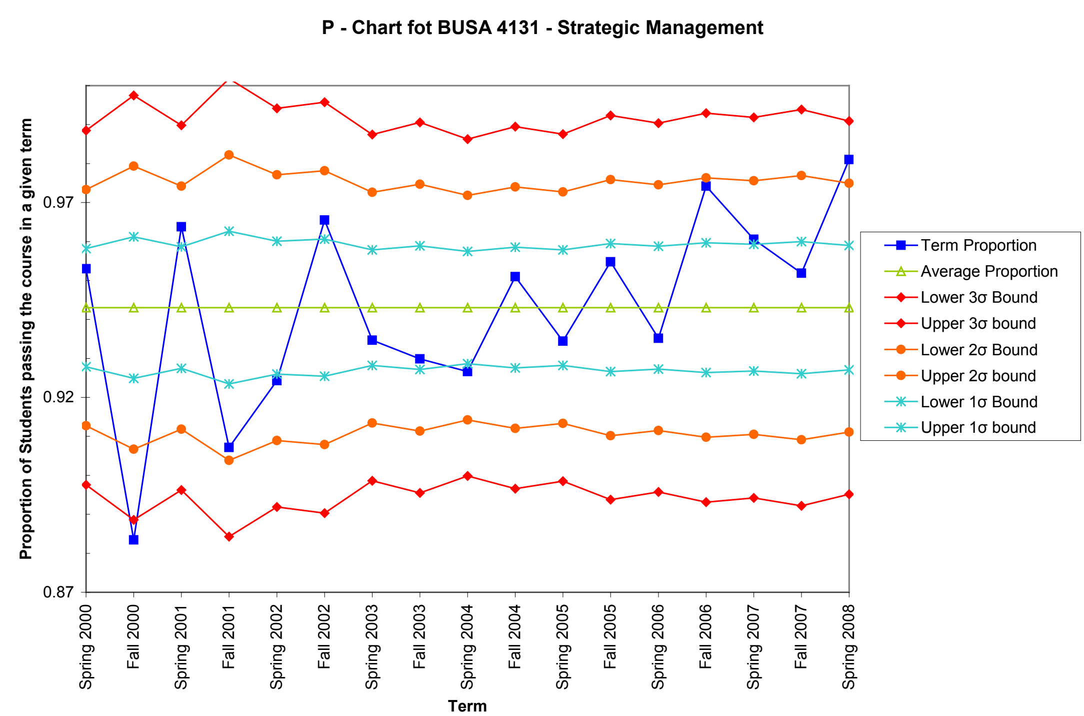


FIGURE 6



ties arise. First, it is possible that the point would not have seemed unusual at the time (if one were looking at a chart with pass rates from 1992 to 2000), the average proportion of students passing may have been lower. Second, it is also possible that the faculty and administration at the time were aware of some special cause variation and responded appropriately. Third, because the percentage passing the course is so high, and the number taking the course in that semester was relatively small, it would have taken only one less failing grade to bring the point within the control limit. Hence, there is a small risk that a Type I error is made in concluding the process was out of control when in fact it was not.

SUMMARY AND DISCUSSION

Just as Shewhart (1931) demonstrated lower defect levels where there was superior statistical control of processes, our study of variation in pass rates for an academic sequence shows that academic courses with lower pass rates exhibit less statistical control. This demonstrates the value of SPC as a tool for academic administrators who seek to improve RPG. From a control charting perspective, the specific proportion (p) of students who pass (shown on the control charts) is not as significant an issue as is the wide variation in this proportion found from semester to semester in certain courses. Unless the special causes of these inconsistencies in pass rates are eliminated, it is very difficult to utilize an approach such as the PDSA cycle to continuously improve student pass rates (and hence progression) through strategies applied to the instructional process. Illustrating this point is one of the primary benefits of this paper – particularly given the lack of penetration of SPC in academic administration.

Student progression through our critical sequence of courses is analogous to progress of material through manufacturing processes. When students enter this critical sequence, those lacking in aptitude and ability get filtered out and do not move to the next course in critical sequence. This means that students with relatively better aptitude and abilities progress to the next course, thereby increasing the student performance in the subsequent courses. This is one common explanation for the increase in passing proportions observed as retained students move to higher level courses. For this reason, it may be more economical and beneficial to set higher standards (which may cause lower pass rates in the lower level classes such as MATH 1232, in order to improve the passing proportion in later classes as well as quality and efficiency of the overall university system. Alternatively, it may be effective to assure a good quality of the raw material (namely student preparedness) by raising the entrance standards. This should have an effect on the pass rate in the first course of the sequence and may actually reduce variability throughout. If either of these alternatives seems unrealistic due to current policies, maybe a leveling remedial course for less prepared students should be a requirement, before they enroll in their first academic classes in the sequence. A recommendation of adjustments to course rigor, such as suggested above, however, needs to be predicated on the ability to control. As we have seen, statistical control has not yet been demonstrated for most of the courses in this sequence. Hence, there is a fundamental need to establish statistical control of the instructional processes – demonstrated through limited variability in semester to semester passing proportions – before our university may effectively pursue this academic strategy aimed at retention. This recognition is a second benefit of our research.

In the context of a management process such as the Deming cycle, ongoing use of statistical control charts enables a department chair to establish a reasonable range (benchmark) for pass rates in any course of interest. This benchmark can be established through an S-D-S-A cycle (Standardize – Do – Study – Act). The Deming Cycle for continuous improvement of processes which have been standardized utilizes four stages: Plan – Do – Study – Act. During the <u>plan</u> phase, instructors for a given course would identify any changes they intend to make to their pedagogy for a given term (e.g., new book, new assignments, different topics, altered pedagogy, etc.). The <u>do</u> phase occurs as the course is taught: instructors would maintain records of student performance as well as information regarding student receptivity to the new approach. Control charts would be most helpful during the <u>study</u> phase, which would involve determining the impact of the change. A course change that led to improved learning, as documented both by an improved pass rate and the records of student performance gathered during the do phase, would be institutionalized going forward. Likewise, innovations that did not work might show on a control chart as an out of control point and be documented and discontinued. Thus, the control chart is critical because it allows the course supervisor and/or instructors to know when pass rates are unusually high or low and to respond in a timely manner. Indeed, it allows for experimentation with teaching methods to result in continuous improvement to RPG by identifying those new instructional techniques that work, and those that do not. Illustrating this relationship between control and improvement is a third benefit of our project.

The Deming cycle is predicated on the presumption that improvement is derived from the application of knowledge. (Evans and Lindsay, 2002). As such, the initial use of statistical control charts can enable administrators to focus on improvement implementation and learning. Looking at Figure 1, for instance, the sample proportion for spring 2007 indicates the presence of some factor that added variability to the educational process. Studying the upward trend and the exceptional progress rate on that year can give administrators great knowledge about the educational process. Such knowledge can be used to consolidate the contributing factors to exceptional results or to uncover factors that need attention and modification. Therefore, as used in this study, the control chart can afford administrators a great means to generate knowledge about the educational process that can guide improvement efforts. Upon stabilization of the process, the ongoing use of control charts enables administrators to predict pass rates, for instance, and, therefore, allocate classrooms and staff courses. Allocation of classrooms and staffing of courses is typically a problematic area due to dependency on budgetary information, which is not always timely. The ability to predict the proportion of students that are likely to advance in a sequence may, at least partially, alleviate this problem.

In summary, this paper presents a new approach to identifying instructional issues in retention, progression and graduation. It demonstrates the use of SPC to analyze the variation related to student academic performance so that root cause analysis can be conducted, and corrective actions developed, by those who supervise instruction. Control limits derived on each chart are dependent on student performance but, once statistical control has been established, future targets may be developed by benchmarking the pass rates of institutional peers and competitors. Additionally, in the current academic climate, with a heavy emphasis on assurance of learning through assessment processes, SPC also provides a means for monitoring relationships between educational quality (i.e., learning outcomes) and academic progression.

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