AC 2009-1489: CAPACITY AND RESOURCE PLANNING FOR AN ENGINEERING TECHNOLOGY DEPARTMENT

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Capacity and Resource Planning for an Engineering Technology Department

Abstract:

In the business world, capacity and resource planning involves the management of production and service resources such that the enterprise is able to respond to the needs of its customers. Choices regarding the quantity, location, type and organization of these resources have a direct impact on the financial success and survival of the corporation. As markets, competition and customer requirements change organizations are often faced with reinventing their production and service systems to adapt to these needs. Contemporary production systems such as lean manufacturing and classical industrial engineering efforts have created many tools and techniques to address the issues of capacity and resource planning. These tools and techniques can be adapted, some more successfully than others, to the management of resources in engineering technology academic operations.

Variability in freshman and transfer enrollment, online learning technology, laboratory and project intensive coursework, retention efforts, the demands of sponsored research and a variety of other issues create a challenging environment for those responsible for providing the resources necessary for effective and efficient operation of an engineering technology department. This paper outlines the use of capacity and resource planning tools and techniques to manage the current operations of an academic department and to plan for likely future scenarios. Techniques and topics include hoshin planning, production strategy options, aggregate planning, Monte Carlo simulation, capacity/flow models, theory of constraints, and heijunka production leveling. This variety of classical and contemporary production tools and techniques are presented and adapted to use in academic operations. Sample applications are presented and findings include highlights of techniques found to be particularly effective as planning and management tools.

Introduction and Background:

Capacity and resource planning involves the management of production and service resources such that the enterprise is able to respond to the needs of its customers. Choices regarding the quantity, location, type and organization of these resources have a direct impact on the financial success and survival of the corporation. As markets, competition and customer requirements change; organizations are often faced with reinventing their production and service systems to adapt to these needs. Contemporary production systems such as lean manufacturing and classical industrial engineering efforts have created many tools and techniques to address the issues of capacity and resource planning.

Management of complex academic operations carries the same challenge of effectively managing academic resources such that the operation can effectively respond to the needs of students, employers, faculty and other stakeholders. Engineering technology departments have the added challenge of requiring resources that generally go far beyond the typical classroom, professor and whiteboard. A simple strength of materials class for example, might involve a primary instructor, lab instructor, classroom schedule, mechanics lab, computer lab, hardware, software, sample materials and industrial application examples. Rather than an in-depth study of one tool, this paper reviews a sampling of techniques in an effort to give the reader insight into tools which might be of specific interest and application to the challenge of a given day.

Production as a Metaphor for Education:

Education is obviously not a production process. In fact, the students we serve might be quite upset to read a paper which equates them to auto parts traveling down an assembly line. Their upset would be justified in that the majority of educational challenges; curricula, learning styles, celebrating achievement, creating motivation, and many others have little correlation to the world of industrial production. However, in the case of capacity planning the connection is quite clear. Production processes and educational enterprises have resources, each with finite capacity. These resources are interconnected and highly dependent on each other's operations in order to produce results. The demand for these resources is often highly variable and the subject of complex forecasting and scheduling efforts. It is possible to extend this production model of education far beyond what is effective or appropriate; here the resources of concern will consist of faculty, labs, equipment and the like, while the demand of interest will be students moving through the system. For the purposes of capacity planning, an academic department can be treated as a service business like an airline or hotel. A challenge common to most service operations is that it is difficult or impossible to stockpile inventory [5]. Unused seats in a class, empty hotel nights, and unfilled seats on a flight can't be stored in a warehouse for use at some unknown future time. These resources are available and consumed, wasted by underutilization or represent a missed opportunity due to a shortage of supply.

Production Strategy Options:

Production systems are often classified by the general operating principles which link customer demand to production activity. Common categories are described below.

Engineer to Order:	Design, production and assembly work begins only after a customer order is received. Example - bridge construction
Make to Order:	Production and assembly of a predesigned product begins only after a customer order is received. Example - yacht production
Assemble to Order:	Assembly from common premade components begins after a customer order is received. Example – home computer production
Make to Stock:	Product is produced based on a predetermined forecast of sales. Example - Offshore production of clothing and small appliances.

For each of these models different tools and techniques are applied to efficiently operate the system and effectively meet customer demand [10]. For example, in an assemble to order system it is critical to have effective tools and techniques to configure orders based on standard components and well designed components which can be assembled to create a wide variety of product options based on a limited variety of stock components. A familiar example of assemble to order systems are computer vendors who allow customers to order and configure their computers online from a prearranged set of compatible options.

Of the four production models offered above, two may relate well to the educational enterprise. Individual students could see a university as an assemble to order system because they choose from an available listing of majors and courses and assemble a degree program. However, from the university administration perspective, classes are scheduled well ahead of the demand from the students. Administrators schedule course and lab sections based on expected demand and hope they are filled by students. Much in the way that a company making toasters builds a production schedule based on forecasted sales, fills the supply chain and then hopes customers purchase the items. In this make to stock model effective demand forecasts and production scheduling processes are critical because the ability to quickly react to changes in customer demand is limited. Resources (faculty, labs, and classrooms) are already committed to scheduled production and empty lab seats can’t be stored for next semester or sold and shipped to another school which has unmet needs.

Aggregate Planning:

Academic operations often have extensive forecasting efforts dedicated to predicting and managing the admission of new students into programs. To effectively forecast the demand for a given course or lab, this inbound forecast must be aggregated with demand from existing students in the major and demand from new and existing students outside the department responsible for the course. In large operations this can become a surprisingly complex endeavor that in many cases is not supported by the information systems at hand.

As an example Figure 1 describes how enrollments in three different engineering technology programs (Electrical/Mechanical Engineering Technology (E/MET), Manufacturing Engineering Technology (MfgET), and Mechanical Engineering Technology (MET) impacts the demand for four different resources (First Year Experience Class, Manufacturing Process Lecture, Manufacturing Process Lab and Writing Lecture).

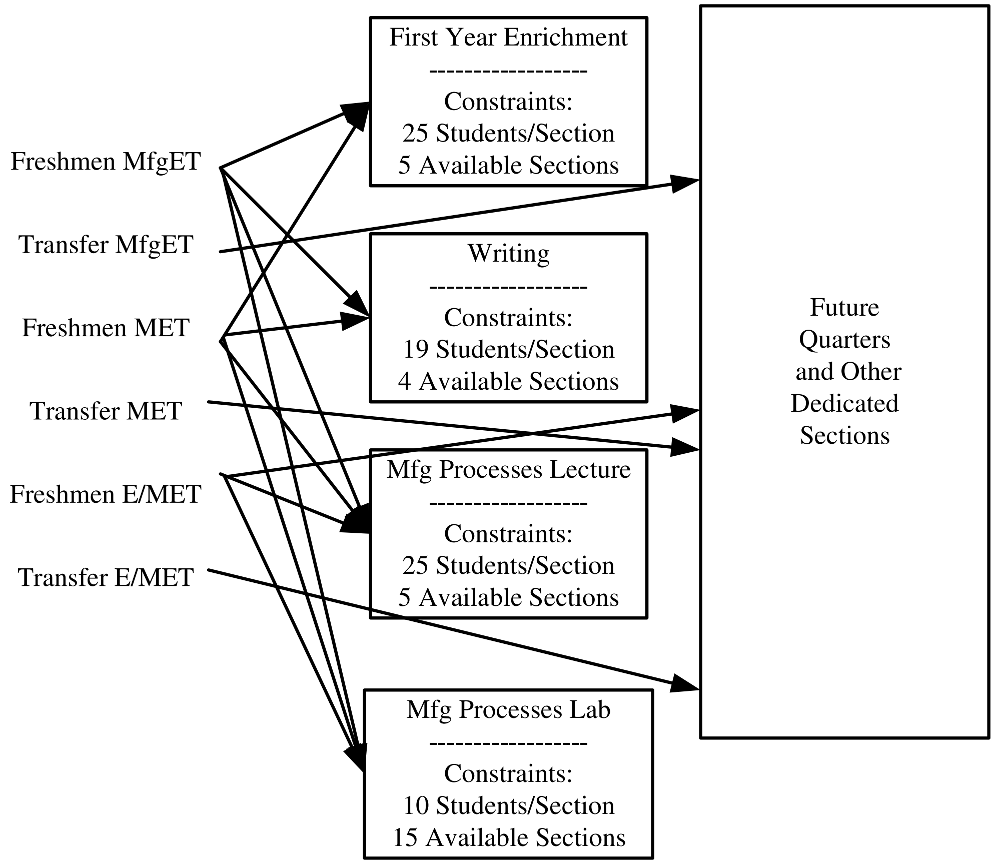

Figure 1: Entering Student Resource Needs

In this case freshmen from MET and MfgET are put in common learning community sections of writing and FYE. Demand for writing is typically reduced by 10-30% due to students with advanced placement credit, and freshmen in all three programs go into manufacturing processes lecture and lab. Transfer students move to a variety of other courses and future sections of a subset of the classes listed.

Monte Carlo Simulation:

Straightforward spreadsheet tools (such as linear regression analysis) are available to support the development of time series based forecasting models of student demand for academic resources. Further, spreadsheet analysis can be made dynamic, rather than static, through the introduction of relatively simple to use Monte Carlo simulation techniques. The tool used here is a simple, dynamic spreadsheet model that generates forecasts of student enrollment, incorporates the uncertainty (variability) associated with those enrollments, and determines the likelihood that the incoming student population will exceed the capacity for a number of academic resources. The forecasts of student enrollment are performed with functionality incorporated in the traditional Excel package, and the dynamic, Monte Carlo simulation capability is provided by a low cost Excel enhancement from Oracle, Crystal Ball.

Consider the time series data shown in Figures 2, 3, and 4 below. The plots show enrollments in each of three Engineering Technology programs for the years 1999 through 2008. Freshman enrollments are indicated with the line labeled "FR", while transfer enrollments are denoted with the line labeled "TR".

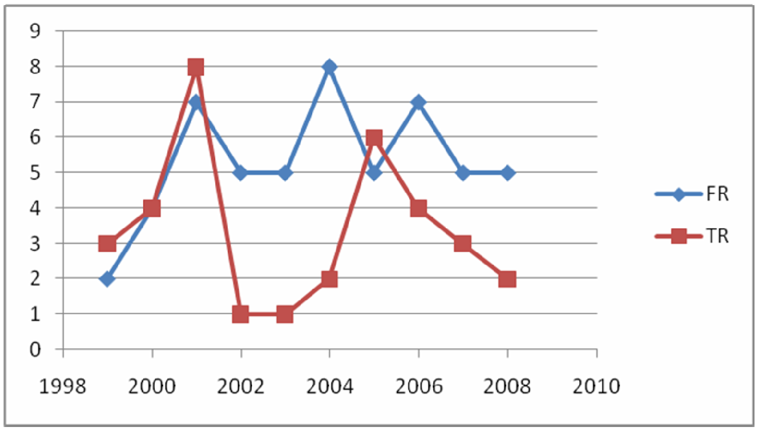

Figure 2: Manufacturing Engineering Technology Enrollments

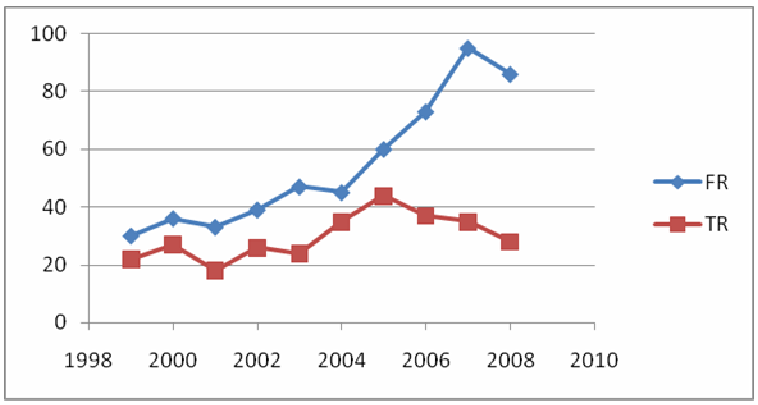

Figure 3: Mechanical Engineering Technology Enrollments

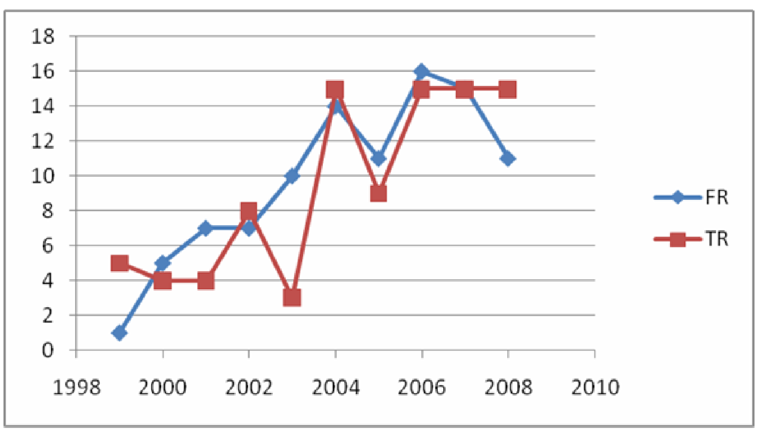

Figure 4: Electrical/Mechanical Engineering Technology Enrollments

The development of a simple forecasting/simulation model is described below. The academic resources that are being examined in this case are utilized by freshman exclusively, so this model will deal with the freshman data only. However, resources that are claimed by transfer students could be reviewed using a similar modeling approach.

The first step in the modeling process is to develop a forecast for annual enrollment of freshmen. The linear regression modeling approach also delivers an estimate of the variability or unpredictability associated with the freshman enrollment processes. Given the model prediction and an estimate of process variability, the analyst can make varying assumptions about the distributional behaviors of the enrollment processes, and thereby generate scenarios that represent these processes. These scenarios can then be evaluated against known resource constraints and points of concern can be readily identified.

Students who enroll in the three programs described above make claim on a number of academic resources as described above in Figure 1. Four resources are modeled here: 1) the MET/MfgET "First Year Experience" course (currently 5 sections can be allocated), 2) the freshman writing course (currently 4 sections can be allocated), 3) an introductory technology course that is required for freshman (currently 5 sections are allocated), and 4) the laboratory section that is associated with the introductory course (15 sections allocated).

Here, a simple linear regression model, describing enrollment (y) as a function of the academic year (x) was developed for each of the three programs. The simple regression approach achieved very good fits for the data from the Mechanical Engineering Technology program and the Electrical/Mechanical Engineering Technology program, generating R^2 values of 0.88 and 0.73 respectively. The fit for the data from the Manufacturing Engineering Technology program was less satisfactory; the R^2 value was 0.16. Estimates of the standard deviation for the enrollment processes in Mech. Eng. Tech, Elec/Mech Eng. Tech., and Mfg. Eng. Tech were 8.6 students, 2.6 students, and 1.66 students, respectively. Here, the assumption is made that these processes follow a Normal distribution. Other distributional behaviors could be invoked if appropriate.

Crystal Ball is an Excel supplement that allows the analyst to introduce dynamic behavior to spreadsheet models. Alterations to the forecast models and "What if" scenarios can be evaluated with relative ease using this capability. For instance, given the modeling assumptions described above, simulated results for total enrollments in each of the three programs for the year 2009 are shown graphically (10,000 trials were conducted for each).

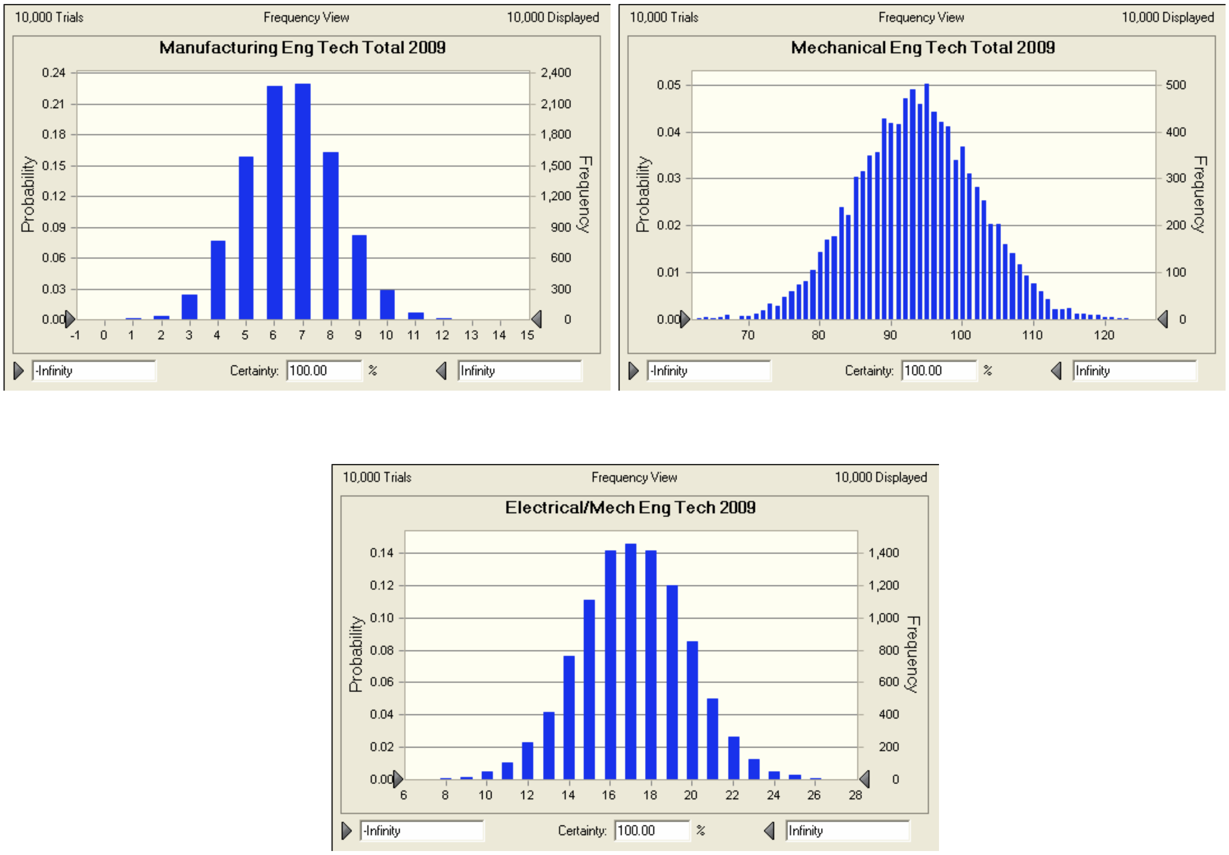

Figure 5: Simulated Freshman Enrollments for 2009

These simulated enrollments can be compared to the available resources in order to determine the likelihood and potential severity of shortages. A five year projection of the likelihood that enrollments will exceed the resource capabilities is given below.

Table 1: Likelihood of Exceeding Resource Availability

Academic Resource	Resource Availability	Probability that demand exceeds capacity in year:				
		2009	**2010**	**2011**	**2012**	**2013**
FYE Sections	5	0.0019	0.0208	0.1203	0.3480	0.6936
Writing Sections	4	0.6660	0.8532	0.9557	0.9918	0.9994
Mfg. Process Lecture	5	0.1871	0.5210	0.8428	0.9757	0.9974
Mfg. Process Lab	15	0.0002	0.005	0.0466	0.2220	0.5780

Note that certain resources are much more likely to be oversubscribed than others. For example it is almost certain that the demand on the Manufacturing Processes Lecture will exceed capacity within the next two years, while it is very unlikely that lab section demand will exceed the available capacity. This might suggest that there could be value in reducing the lab capacity if that could be translated into additional class capacity. Again, the use of a Monte Carlo modeling approach such as that described here would enable that type of comparison.

Capacity/Flow Models and the Theory of Constraints:

Table 1 above suggests a priority for adding capacity in different resource areas. Another process is a simple assessment of bottleneck conditions. A bottleneck or critical constraint is any resource with capacity less than the current demand [7]. If the current demand is unknown, the the lowest capacity resource in the process flow is the likely bottleneck. For example, the diagram below represents the suggested sequence of first year technical courses in a Manufacturing Engineering Technology Program.

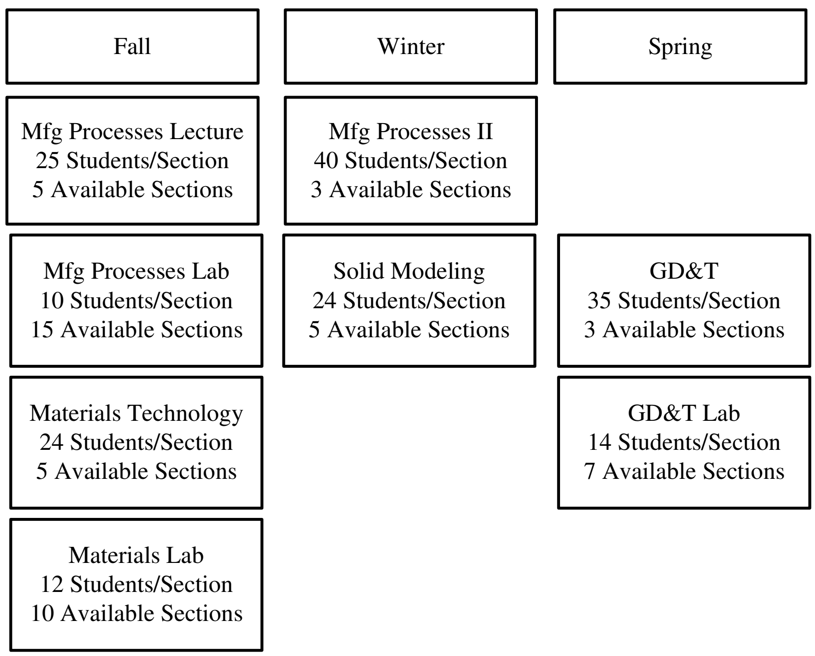

Figure 6: Sequence of Typical Manufacturing ET First Year Technical Courses

The resource with the smallest capacity here is the GD&T Lab at 98 seats per quarter. This Lab may well be a system bottleneck. The problem, however, is that students can enter and exit this flow at somewhat random places. For example transfer students often start in Manufacturing Processes II in winter quarter, adding to demand at that node. Students also may fail or withdraw from a course, reducing downstream demand and adding unexpected demand in future quarters. So, these models can help gain an overview of critical points in the process and help document the current capacity of nodes in the system, but have limited utility when considering overall performance. Predicting and understanding variability in demand for individual courses and labs as shown in the previous Monte Carlo simulation example may be a better approach when trying to eliminate bottlenecks, and underutilization of existing capacity.

Hoshin Planning:

Hoshin Planning is a direction setting and policy deployment technique commonly used as a part of the Toyota Production System to identify critical key issues related to the success of an enterprise and set in motion goals, strategies and plans to move closer to a desired future state [6]. A disciplined form of strategic planning and goal setting, this process and similar efforts to make major changes to an academic department and its operations will generally have dramatic downstream effects on how resources are managed and how success is measured in the enterprise. An example in the operations of the department under study is the growing importance of sponsored research at the university as a whole. This focus has a downstream impact on the effective use of resources in that it is now unwise or impossible to schedule labs for 30-50 hours per week of instruction as was common in the past. As scholarly and research work increases, lab schedules, layouts and equipment plans need to include time and attention to ongoing research projects and the needs of full time graduate student researchers. For strategic initiative implementations such as this, a key success factor is to ensure that the measures used to evaluate operational performance continue to match the evolving goals of the operation. In the case of our engineering technology department the goals of our capacity utilization improvement efforts will need to clearly link and support the strategic goals of the university, our college, department and the improvement opportunities identified by the regular operation of our TAC of ABET based continuous improvement system.

Heijunka Production Leveling:

A key element in the Toyota Production System is the concept of heijunka production leveling in which production volume and product variety is spread evenly over the period of production [8]. In a manufacturing example this relates to creating processes with the flexibility to frequently change the product being manufactured, instead of running a production system in large batches. It can best be seen in Toyota assembly lines where two different models flow down the same assembly line and the sequence is purposefully alternated so that a large quantity of one model does not flood the system and create a shortage of another model. It is difficult to equate to a service or education example because most services can't effectively be inventoried, so running in large batches is not feasible. However, the data in Figure 7, taken from an engineering technology department, shows that the production of courses is not well balanced on a quarter to quarter basis. This creates very high workloads for faculty and labs in the fall and effectively forces the department to perform primarily teaching duties in fall, reserving research, service and other scholarly activities for winter and spring. This has the same effect as running large batches, creating a shortage of research and service capacity in fall quarter and excess demand for research resources in winter and spring quarters.

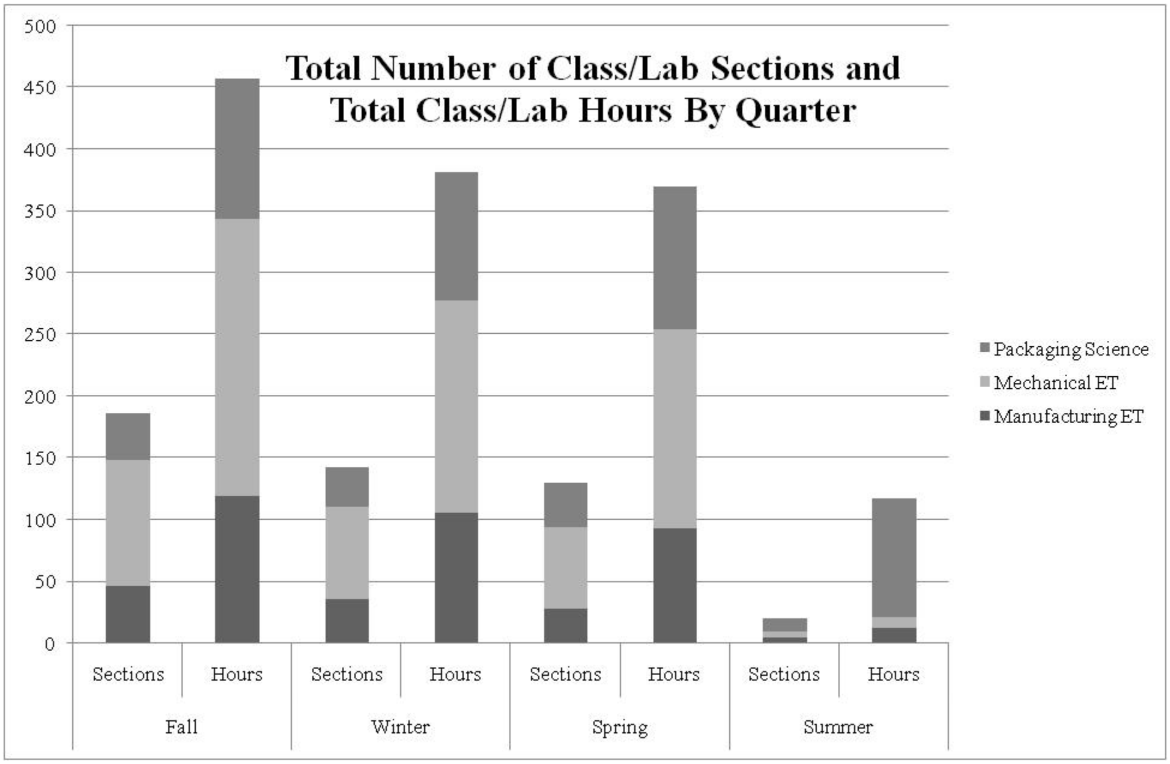

Figure 7: Total Class/Lab Hours and Sections by Quarter

An opportunity for improvement would be to identify high demand technical courses that can be moved from fall to other quarters, and required service department courses that can backfill and balance the workload inside our department.

Findings and Conclusions:

The study of capacity and resource management has many applications in the field of educational operations. Of the subjects highlighted in this paper the Monte Carlo based evaluation of the likelihood of future resource shortages seemed to provide the best insight to future challenges in the operation of our department. Other tools like the heijunka based look at balancing the workload across the academic year, simply quantified something that has been a known issue in the department under study for quite some time. The best overall benefit, however, was based on the system level understanding gained by the process of data collection, process investigation and calculation of capacities. This process uncovered and clarified complex hidden problems and presented details on the operation which would have been impossible or unlikely to be discovered using existing reports, performance metrics and evaluation techniques. The department expects to continue use of these tools in order to proactively approach the ongoing measurement and improvement of the operational performance of our educational processes.

References:

1. “Facilities Planning”, James A. Tompkins, John A. White, Yavuz A. Bozer, Edward H. Frazelle, J.M.A. Tanchoco, and Jaime Trevino, Johns Wiley and Sons
2. “SKED: A Course scheduling and Advising Software”, Tarek Sobh , Damir Vamoser , Raul Mihali, Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition
3. “Updating the Objectives of a Manufacturing Engineering Technology Program”, Daniel P. Johnson Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition
4. “A Model to Assess and Balance Faculty Workload”, David Gibson , Don Rabern , Vic Cundy Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition
5. “Match Supply and Demand in Service Industries”, W. Earl Sasser, Harvard Business Review, 1976
6. “Industrial Technology Program Enhancement: The Importance of Strategic Planning”, Dr. Dan C. Brown and Dr. Ron Meier”, Journal of Industrial Technology, Volume 21 Number 4, October –December 2005
7. “The Goal – a Process of Ongoing Improvement”, Eliyahu M. Goldratt and Jeff Cox, North River Press
8. “Toyota Motor Manufacturing, USA Inc”Harvard Business School Case Study 9-693-019, September 1995, Harvard Business School Publishing
9. “Lean Thinking”, James P. Womack and Daniel T. Jones, Simon & Schuster
10. “Manufacturing Strategy Text and Cases”, Terry Hill, McGraw-Hill Higher Education