Developments in Business Simulation and Experiential Learning, Volume 26, 1999

THE ABC'S OF TEACHING THE THEORY OF CONSTRAINTS TO UNDERGRADUATE BUSINESS STUDENTS

Arup Mukherjee, University of West Florida
Walter J. Wheatley, University of West Florida

ABSTRACT

For many years Production and Operations (POM) texts have tried to stay current with the latest methods of improving quality and productivity. Materials Requirements and Planning I and II were some of the earlier approaches that have been dealt with in POM texts. Then came a tide of quality related techniques which included methods such as Total Quality Management and Just in Time which were dealt with in great detail in POM texts. However, the Theory of Constraints (TOC), a method of improving productivity and profitability by reducing bottlenecks in operating systems, has not been dealt with in the detail the authors of this paper would like to see. To encourage more attention to having TOC dealt with in more POM texts, the authors have broken down this somewhat complicated topic into its simplest terms and present a very simple illustration of teaching this valuable POM topic.

INTRODUCTION

Improvement of manufacturing operations has been a critical challenge for business managers all over the world for the last two decades. Many tools, techniques and approaches have been proposed and tested in actual use. In the United States the technique of 'materials requirements planning' (MRP) has been used extensively. Subsequently, the Japanese succeeded in perfecting some of these techniques and created some of the most admired manufacturing companies of the world. Important techniques that the Japanese successfully used included 'Just In Time' (JIT) and 'Total Quality Management' (TQM). Companies in every country have since then attempted to incorporate these techniques in their operations. In addition to the above, the technique of the 'Theory of Constraints' has been proposed and used successfully by companies in the United States. In the decade of the 1990's it is difficult to find a renowned manufacturer who has not attempted to incorporate one or more of these approaches in improving their operations.

The schools of business have recognized the importance of these techniques and accepted the challenge of educating business students in the science and art of these approaches. The techniques of JIT and TQM are now widely taught in most Operations Management courses. However, teaching of TOC is relatively new and is somewhat difficult in the context of an undergraduate production management class.

The purpose of this article is to describe an illustrative example on the use of the TOC approach that highlights the power of the approach and its suitability for use in an undergraduate business class. First, we present a discussion of the popular techniques currently used to improve manufacturing operations. This is followed by a broad overview of the theory of constraints. Then we present the illustrative example that makes it easy to understand the underlying concepts. Finally, we discuss the benefits of use of this particular exercise in teaching TOC.

TECHNIQUES FOR IMPROVING OPERATIONS

In the time period from 1970 to 1985, manufacturing managers in the United States had experimented with, augmented and implemented various versions of the MRP technique (Chase and Aquilano, 1992). MRP is basically a system of planning and scheduling materials that would be required for manufacturing operations. According to Adam and Ebert (1989), implementations of MRP systems have led to inventory reductions, reduction in production and delivery lead times, more realistic commitments of delivery schedules and fewer unplanned interruptions in the plant.

In the 1980's the JIT technique was successfully implemented in several Japanese manufacturing firms. The JIT approach was first used at the Toyota Motor Company. The key idea is to carry out manufacturing activities like processing, movement of materials and procurements as and when they are needed (Stevenson, 1990). As a consequence, very little inventory is present in the system. When implemented successfully, this approach leads to lower inventory, reduced requirements of space, reduced scrap, reduced manufacturing lead times, and increased productivity levels.

Another powerful technique that has contributed to the Japanese success in manufacturing is TQM. It has been suggested that TQM is an innovation that has revolutionized manufacturing (Chase and Aquilano, 1992). TQM was taught to the Japanese by two quality experts from the United States, notably Dr. W. E. Deming and Dr. J. Juran. The basic idea is that controlling the process rather than inspecting items that come from the process is the key determinant of quality. So the focus needs to be on process control through understanding the causes for variation in the process. This would need participation and training of everyone involved with one or more aspect of the manufacturing operations. Additionally, TQM focuses on understanding customer needs and carrying out continuous improvements to deliver better products and services to the customer. TQM has had such a big impact on product quality of the Japanese automobile manufacturers, that manufacturers of every kind, size and country have adopted it. TQM is now considered to be a primary strategic tool for survival of the firm.

OVERVIEW OF THEORY OF CONSTRAINTS

While the above techniques have successfully transformed manufacturing operations, there have been instances where one or more of the techniques failed to deliver the promised results because of existence of unrecognized capacity constraints in various parts of the manufacturing system. Dr. E. Goldratt developed a technique for improving operations in this kind of scenario (Goldratt and Cox, 1984). The technique was incorporated into appropriate computer software and used successfully in many manufacturing firms. This technique came to be known as the 'Theory of Constraints' (TOC) and is discussed next.

Goldratt (1984) argued that while an organization may have auxiliary purposes such as creating jobs, buying and selling products, increasing market share etc, its main goal is to make money. If a firm does not make money it will not survive and will not be able to meet its auxiliary objectives. However, in every system there exists constraints at any given time that prevent the system from achieving its main goal. Thus, if these system constraints (or bottleneck constraints) are properly managed, it would be possible to achieve ever higher levels of the main goal. Finch and Luebbe (1995) describe the example of a firm where production was getting backed up at six injection molding machines at Howmet Turbine's plant in La Porte, Indiana. Management found the constraint to be an insufficient number of workers operating the machines. When one extra worker was assigned to this machine center, output increased by 40%.

How important are these concepts to businesses in 1998? Take the example of Boeing, the largest manufacturer of commercial aircrafts in the world.

In the last three months, Boeing has lost market share and its stock price has dropped because of its inability to meet customer demand due to production bottlenecks. So the phenomenon of production bottlenecks is very real and has the potential for large negative consequences. It is important for business students to be familiar with the phenomenon and what to do about it if it is encountered in the workplace.

As manufacturing organizations have become complex, it is increasingly difficult to manage the manufacturing activity. TOC helps managers separate those resources and activities that are critical from those that are trivial. By focusing attention on the critical resources and activities, management is able to identify bottlenecks in the system and take steps to eliminate them.

The five steps in the general approach of TOC is summarized in Table 1 and discussed below.

TABLE 1
FIVE STEPS IN THE GENERAL APPROACH OF TOC

1. Identify System Constraints.
2. Decide how to exploit system constraints
3. Subordinate everything else to that decision
4. Elevate the system constraints
5. If system constraint has changed go back to step 1

The first step is to identify the system's constraints. This may be something like availability of raw materials, time or money.

The second step is to make sure that the particular constraint is utilized in the best manner possible for achieving the system goal. If time on machine A is the bottleneck, the idea is to utilize time on machine A in a manner that maximizes the money made.

The third step is to make activities at other centers subordinate to activities at the bottleneck constraint. The main impact is to schedule activities so that the bottleneck resource can work all the time.

The fourth step is to elevate the system's constraints. The basic idea is to take steps that enhance capabilities at this bottleneck constraint. For example, if the system constraint is a machine, elevation may include buying similar machines to add to capacity..

As a consequence of the above steps, it is quite possible that a previously identified bottleneck constraint no longer remains a system constraint. The fifth step suggests that the TOC process needs to be repeated from step 1 so that work may begin on a new system constraint. The TOC process is a continuous process and systematically leads to identification and elimination of system constraints so that the system may achieve ever higher levels of its main goal.

ILLUSTRATIVE EXAMPLE ON TOC

We consider a production system for making 2 products. The relevant data about demand, selling prices, costs, resource levels are summarized in Table 2. Demand for products P and Q are 150 and 100 units respectively per week. The selling price for P is $100 per unit and $80 per unit for Q.

TABLE 2
PRODUCTION PROBLEM DATA

	P	Q
Demand per week	150	100
Selling price	$100	$80
Raw material costs		
RM1	$20	
RM2	$10	$10
RM3		$15

P requires one unit of raw material 1 at a cost of $20 and one unit of raw material 2 at a cost of $10. Q requires one unit of raw material 2 at a cost of $10 and one unit of raw material 3 at a cost of $15. An unlimited supply of all three raw materials is available.

Both P and Q require a total of five minutes of production time in work center A. In work center B, product P requires six minutes of production while Q requires five minutes. The total capacity of both work center A and B are constrained to 2400 minutes per period. The operating expenses are $10,000 per week. This problem will be referred to as Scenario 1. Since there is unlimited raw materials, the only possible constraint would be in processing time. The first step is to carry out a capacity analysis as shown in Table 3.

From the capacity analysis, it is determined that there is ample processing time. Thus there is no constraint in this situation and the entire demand for 150 units of P and 100 units of A can be met. A weekly net profit for this demand level is shown below in Table 4. The total sales revenue is $16,000 while the operating expense is $10,000. This leads to a weekly net profit of $6,000.

TABLE 3
CAPACITY ANALYSIS FOR SCENARIO 1

Work center	Load for P	Load for Q	Total minutes required	Total minutes available	Percent required
A	750	500	1250	2400	52%
B	900	500	1400	2400	58%

TABLE 4
PROFIT ANALYSIS FOR SCENARIO 1

Best Mix	Contribution per unit	Total Contribution	Weekly Operating Expenses	Weekly Net Profit
150 units of P	$70	$10500	$10000	$6000
100 units of Q	$55	$ 5500		

Scenario 2

Now consider the situation when processing time per unit has doubled for work center B. In other words, P and Q require 12 and 10 minutes of processing time respectively in Department B. The capacity analysis presented in Table 5 reflects a constraint on work center B. Work Center B is thus the system constraint in this scenario. The next step is to identify the product that generates the highest margin per unit resource. This is shown in Table 6. Product P has the higher return of $5.83 per constraint unit. Thus we should subordinate everything to produce as many P's as possible.

The market demand of 150 units of P only uses 1800 minutes at work station B. This leaves 600 more minutes on work station B with which we can make 60 more Q's. Thus, for this scenario, the weekly net profit is found to be $3,800 (Table 7).

TABLE 5
CAPACITY ANALYSIS FOR SCENARIO 2

Work center	Load for P	Load for Q	Total minutes required	Total minutes available	Percent required
A	750	500	1250	2400	52%
B	1800	1000	2800	2400	117%

TABLE 6
COMPUTATION OF RETURN PER CONSTRAINT UNIT IN SCENARIO 2

Product	Contribution per unit	Use of constraint	Return/constraint unit
P	$70	12 min.	$5.83
Q	$55	10 min.	$5.50

TABLE 7
PROFIT ANALYSIS FOR SCENARIO 2

Best Mix	Contribution Per Unit	Total Contribution	Weekly Operating Expense	Weekly Net Profit
150 units of P	$70	$10500	$10000	$3800
60 units of Q	$55	$ 3300		

DISCUSSION

The example on theory of constraints illustrates many important production management concepts to an undergraduate business audience. The more important concepts are summarized below.

a) The most important concept is that of the bottleneck resource. Students become aware that capacity of the bottleneck resource determines the capacity of a production system.

b) The students learn that in order to increase the capacity of a production system, a manager has to first identify the bottleneck resource and then take steps to increase the capacity of this resource.

c) Students learn that bottlenecks arise in production systems in various guises. Sometimes processing time at work centers is a bottleneck. At other times raw material availability is a bottleneck. At some other times availability of capital is a bottleneck.

d) As a corollary, students learn a simple technique to maximize returns when bottlenecks are present. All that needs to be done is to find the bottleneck resource and compute the "return per unit use of bottleneck resource." The best production strategy would be to maximize production of the item with the highest "return per unit use of bottleneck resource."

CONCLUSION

Business managers have continuously sought ways to improve production operations. The techniques of MRP, JIT and TQM are well established production management techniques and have been taught to business students for quite some time. However, the "theory of constraints" has recently emerged as a powerful technique to improve the efficiency of a production system. This article describes an illustrative example that may be used to teach this technique to undergraduate business students. The illustrative example is useful in explaining the concept of the bottleneck resource and the concept of system capacity being constrained by capacity of bottleneck resource. Students learn that in order to increase system capacity the first step to be taken would be to increase capacity at the bottleneck resource. Students also learn that in presence of a bottleneck, a production strategy that maximizes production of products with higher contribution per unit of bottleneck resource consumed actually leads to greater profits for the firm.

REFERENCES

Adam, E. E. & Ebert, R.J. (1989). *Production and Operations Management: Concepts, Models and Behavior*. Englewood Cliffs, NJ: Prentice Hall.

Chase, R. B. & Aquilano, N.J. (1992.). *Production and Operations Management: A Life Cycle Approach*. Boston, MA: Irwin.

Finch, B. J. & Luebbe, R.L. (1995). *Operations Management: Competing in a Changing Environment*. New York: Dryden Press.

Goldratt, E.M. & Cox, J. (1984). *The Goal: Excellence in Manufacturing.* Croton-on-Hudson, N.Y.: North River Press.

Stevenson, W.J. (1990*). Production/ Operations Management*. Boston, MA: Irwin.