CHAPTER 9

Revenue Management and the Theory of Constraints

Eli Goldratt popularized the theory of constraints (TOC) in his well-known instructional novel, *The Goal*. What he termed the TOC was a renewal and extension of the long-standing scarce resource problem in economics. The TOC concept offers insight into some revenue decisions and also expands the capacity concepts discussed in the preceding chapter.

TOC Financial Measurement System

A very lean financial measurement system is one of the features of TOC. Goldratt argued that managers should focus on three measures, which he named *throughput*, *inventory*, and *operational expense*.

Throughput represents what the company generates through sales. It is typically measured as the revenue value of output less *truly variable* costs. Goldratt would argue that the only significant cost that is truly variable is the materials cost of the product. Some lesser costs that might also be truly variable could include sales commissions, if applicable, and perhaps power costs. But as a practical matter, throughput is measured as selling price minus materials, essentially a net revenue or value-added concept.

Inventory in a TOC system does *not* take on its usual accounting meaning of a stock of merchandise or materials. Rather, inventory represents *all* productive resources the company uses in order to operate and generate throughput. Thus, *inventory* includes inventories in the conventional sense, along with all other productive assets, both tangible and intangible: land, buildings, equipment, vehicles, technology, and so forth.

Operational expense is defined as all the costs needed to turn *inventory* into *throughput*, or all costs necessary to operate the enterprise. Labor, utilities, maintenance, insurance, selling and administrative, and similar costs are all grouped under the broad heading of *operational expense*.

The TOC financial measurement system has little use for the timing issues brought about by accrual accounting. Therefore, accounts receivable, accounts payable, accrued liabilities, and prepaid assets are not computed or considered. The system is close to cash accounting, and the focus is internal measurement, not external reporting. Similarly, issues of how the firm is financed are also ignored. Debt and equity financing, interest costs, and cost of capital are not considered.

In terms of desired outcomes, more throughput is preferred to less, and lower inventory and operational expense are preferred to higher amounts. Trade-offs are usually involved in any decision. An action is unambiguously good if it can increase throughput without increasing inventory and operational expense, or if it can decrease inventory or operational expense without decreasing throughput. In short, *improving one measure without harming the other two is desired*. When this ideal outcome cannot be achieved, the trade-offs need to be considered by management.

Note that the traditional applications of revenue management fit easily into this measurement context—to increase throughput (revenues net of any variable costs) without increasing the (fixed) operating cost base and without adding capacity (i.e., not increasing *inventory*). In the TOC context, *throughput* is king; the goal is to achieve more throughput while keeping *inventory* and *operational expense* under control. Achieving reductions in the latter two is desirable but secondary to growing throughput. In summary, TOC is very much a revenue management approach and only secondarily a cost management approach.

Revenue Focus Versus Cost Focus

In *The Goal*, Goldratt tells the story of a plant manager struggling to keep his plant alive, because it is plagued with many of the problems of an aging manufacturing facility: high costs, large inventories, long lead times, and poor delivery performance. In their initial meeting, Alex Rogo (the plant manager) tells Jonah (the personification of Goldratt) about a new, highly automated machine recently installed in the plant. Alex insists that the new machine is really helping, and that efficiency measures are very impressive—high utilization and low unit costs. Jonah is skeptical, and correctly guesses that the plant continues to lose money, miss its delivery targets, and fail to get product out the door, while its inventories are skyrocketing. Jonah's guess correctly describes the situation, and his insight gets Alex's attention, as he faces a deadline to turn the plant around or have it closed. This encounter leads to a gradual but ongoing implementation of TOC principles that eventually saves the plant.

This episode leads to the first critical idea, namely that generating throughput (revenue management) is more important than cost reduction. Goldratt goes so far as to suggest that an excessive focus on efficiencies and cost management is actually harmful, because it distracts the management's attention from the key task of enhancing throughput. In the situation in the story, the automated machine's numbers, and indeed those for most of the plant's equipment, were good because machines and manpower were kept busy all the time doing *something*, resulting in high efficiency and favorable per-unit costs for the components being processed. But were they doing the right things? Some key component or assembly was often found to be lacking, which prevented shipping the customer's order on a timely basis. Meanwhile, the inventory of many other components was growing. The result was unhappy customers, low revenue, high costs, and a growing stockpile of raw materials, work in process, and some finished goods.

Example of Excessive Cost Focus

You are the manager of a component production department within a large manufacturing company. Your department makes a single component, VG-7, which is used in assembling one of the company's major products. There are no other uses or external markets for VG-7. Further, your department is not equipped to make any other products. The assembly department tells you how many units of VG-7 are likely to be needed each day. These requirements are available to you, on an estimated basis, a month in advance. Estimates are typically quite close to actual requirements, which are provided weekly.

Operating costs for your department are $50,000 per day, including labor, machine costs, and other overhead—all costs except materials.

By union agreement, all employees work an eight-hour day, five days a week. They can be dismissed early, but are still paid for eight hours each day. Overtime is allowed, but one of your managerial objectives is to minimize overtime costs. In addition, you are judged on your daily cost per unit of the product. Your department works a single eight-hour shift, and is capable of producing 10,000 units of VG-7 per day. The material cost for VG-7 is one dollar per unit. A three-day inventory of VG-7 is maintained to allow for unforeseen production disruptions.

Today, after five hours of the eight-hour shift, your department has completed 6,250 units, which is all that assembly requires today. Your actual requirements for the coming week, and your estimated requirements for the coming month, are all in the range of 6,000 to 9,000 units daily. Your assistant asks if you wish to shut down the department for the day and send the employees home, or continue production for the remaining three hours.

This scenario represents a typical cost-focus situation. The decision on cost grounds would be to continue working. If employees are sent home after five hours, today's unit cost of VG-7 would be nine dollars per unit:

Producing 6,250 units costs \$50,000 + (6,250 × \$1) =
\$56,250 or \$9 per unit

Continuing to work for the full eight hours will reduce that unit cost to six dollars per unit:

Producing 10,000 units costs \$50,000 + (10,000 × \$1) =
\$60,000 or \$6 per unit

Although producing 10,000 units at a unit cost of \$6 may seem more attractive, such a decision would violate TOC principles. Since today's demand for this component is 6,250 units, no additional revenue (throughput) can be generated by producing more units of VG-7. Further, production requirements for the foreseeable future are well below the 10,000-unit-per-day capacity of the department, and an inventory exists to cover unforeseen emergencies. Because there is no need to build inventory, the best decision is to stop today's production at 6,250 units. This decision is consistent with the principles of *The Goal*, in that continuing production to 10,000 units per day increases *inventory*, probably increases *operational expense* at least to the extent of holding costs for the additional inventory, but leaves *throughput* unchanged.

Using average cost as a performance metric, as just seen, is generally a bad idea because it encourages the behavior of full *activation* of resources, whether productive or not. One of the principles of TOC is that *activating* a resource (having it perform work) is not the same as *utilizing* the resource (generating throughput). Indeed, under TOC, most resources (including human ones) should *not* be working all the time. It is virtually impossible to have exactly the right amount of each capacity resource; resources should be activated only to the extent that they generate throughput. Thus, the company is better off by idling the department after five hours, even if employees are paid for a full eight-hour shift.

The Presence of Constraints

Central to the TOC is the notion that a revenue-generation system must face one or more *constraints*—limitations on its throughput capacity. If constraints did not exist, throughput could increase without limit, which we observe is not the case. A constraint is any factor that limits throughput. The constraint may be physical (an element of productive capacity or some limitations on availability of materials), external (lack of sufficient demand), or policy based (managerially imposed, such as a single-shift operation). Thus, a typically full aircraft route faces a physical constraint (lack of more seats), whereas an aircraft route only 50 percent full faces a market constraint (lack of demand or perhaps lack of sales effort).

Although one or more constraints on throughput necessarily exist, Goldratt would argue that relatively few are active at any one time, thus making it possible to actively manage the constraints.

Revenue Management Under Constraint Conditions

Managing revenues (throughput) in the face of constraints involves the five-step process outlined in *The Goal*:[1]

1. Identify the current constraint(s). What factors are currently limiting throughput or revenue generation?
2. Decide how to generate the most throughput from the constraint. An illustration follows in the next section.
3. Subordinate everything else to the earlier decision. Throughput is king; do not be distracted by other goals.
4. Seek ways to relax or bypass (*elevate*) the constraint. How can more throughput be generated in the face of the current constraint?
5. If, via the preceding process, a constraint is eliminated, return to Step 1, find the new constraint, and go through the process again. Beware of inertia, of thinking that once a constraint is removed, the problem has been solved.

Example of Managing Throughput Under Constraint Conditions

Walden's Wide World of Furniture manufactures unfinished furniture.[2] A small production unit in Jamestown specializes in two items: an end table and a footstool. These are just two of many items that Walden produces, but they are the only items produced in the Jamestown facility.

For each item—end tables (ET) and footstools (FS)—the manufacturing process involves three machines: a table saw (Department A), a jigsaw (Department B), and a sander (Department C). Jamestown has two of each of these machines and one operator for each machine; the operators are not cross-trained. After the component pieces are made by processing on each of the machines as needed, the item is put together by the assembly department (Department D). The Jamestown site thus has four production resources and two employees in each department.

ET sell for $90 each, and Walden can sell up to 200 units per week. Raw material for an end table consists of one piece of 1-inch round maple stock, which costs $18, and one piece of 12 inch × 16 inch × 1 inch maple, which costs $20. Production and assembly are relatively simple:

- The round maple stock begins in the table saw department (A) where it is cut into pieces for the legs in 15 minutes. Then the legs are sanded (C) for 10 minutes.

- The 12 × 16 × 1 piece goes to the jigsaw (B) and is shaped, taking 15 minutes. The shaped piece then requires five minutes to sand (C).
- Finally, all pieces go to Department D where they are assembled using small metal brackets (cost is $6 per set); assembly takes 10 minutes. Total production time for an end table is 55 minutes.

FS sell for $100 each; at most, 100 of these are sold each week. Each footstool requires one piece of the 12 × 16 × 1 maple and one piece of 2-inch round pine stock, which together cost $18. As with the ET, production and assembly are relatively simple:

- The 12 × 16 × 1 piece goes to Department B and is shaped, requiring 15 minutes.
- The shaped piece then is sanded in five minutes (C). (This is identical to the piece that is used in ET.)
- The round pine stock goes to the table saw (A) and is cut into pieces for the legs; this step takes 10 minutes.
- The legs now go to the jigsaw (B) where notches are cut for the cloth upholstery, taking 15 minutes. (The legs are not sanded, because they will be hidden by the upholstery; Walden sells this product as unfinished furniture, without the upholstery.)
- All pieces then go to assembly (D), which takes five minutes. The total production time for a footstool is 50 minutes.

Each department employee works a guaranteed 40 hours per week and receives pay and benefits equal to $15 per hour. It costs a total $11,200 per week to operate the plant, including the supervisor's salary, wages and benefits of the eight production workers, heat, lights, rent, and so on.

The supervisor currently faces two problems. First, headquarters has just instituted a new planning process and, as part of this process, she must submit a profit target for next week. Second, an engineering student intern from Jamestown Community College just presented her with his report in which he recommends purchasing a different type of jigsaw. The new equipment would cost $10,000 and would reduce the time for

Department B to shape each piece from 15 minutes to 14 minutes, but unfortunately would increase the time for Department C to sand each piece from 5 minutes to 7 minutes.

The supervisor prepared an initial weekly budget, based on the production and sale of 200 ET and 100 FS, the maximum projected demand for these products. Her budget resulted in a projected profit of $4,200. The projected profit seemed a little high, but she checked her figures and everything seemed fine. She noted that her budgeted production required 266.67 hours of production labor (see later for this calculation), well below the 320 hours available. She also wondered whether she should use the extra time to produce some tables or FS for inventory, as Walden was about to begin a new advertising campaign for its products in the hope of increasing demand.

As the supervisor tried to decide what profit figure she should commit to for the next week, she also tried to figure out how to tell her intern that his recommendation unfortunately ignored a critical variable, product cycle time, and that what she needed was a way to reduce the time required to produce ET and FS, not increase it.

Analysis and Discussion

This case is designed to illustrate the TOC principles set forth in *The Goal.* The following are the five steps of managing in the face of constraints:

1. Identify the constraint.
2. Decide how to exploit (get the most out of) the constraint.
3. Subordinate everything else to Step 2.
4. Attempt to elevate the constraint.
5. If a constraint is broken, return to Step 1.

Walden is a two-product, four-process situation. Fixed capacities exist for the four processes (80 hours each, per week).

Recreate the Supervisor's Budget The budget is based on maximum output (market demand) for both ET and FS

Revenue:

200 ET at $90	$18,000
100 FS at $100	$10,000
Total	$28,000

Expenses:

Materials	Labor and overhead	Materials + labor and overhead
200 ET at $44: $8,800	$11,200	$23,800
100 FS at $38: $3,800		
Total materials: $12,600		
Projected profit (revenues – expenses)	*$4,200*	

Time required for production:

200 ET at 55 minutes	11,000 minutes
100 FS at 50 minutes	5,000 minutes
Total	16,000 minutes = 266.67 hours

Note: The total time calculated is less than the 320 hours available, so it seems feasible.

The initial budget shows an expected profit of $4,200, based on planned maximum production of each product (200 ET and 100 FS). Although there was enough *total* time to achieve this output, no account was taken of the time required on a process-by-process basis.

Diagram the Production Process In a simple situation, diagramming the process as shown in Figure 9.1 may be sufficient to identify the constraint. Note that the steps involving Raw Material 2 (RM2) were common to both products. In more complex situations, determining the constraint(s) may not be so easy.

What Is the Constraint in the Process? Determine how much time each product requires of each resource, then show the maximum weekly output of that product that can be achieved with each resource (see Table 9.1).

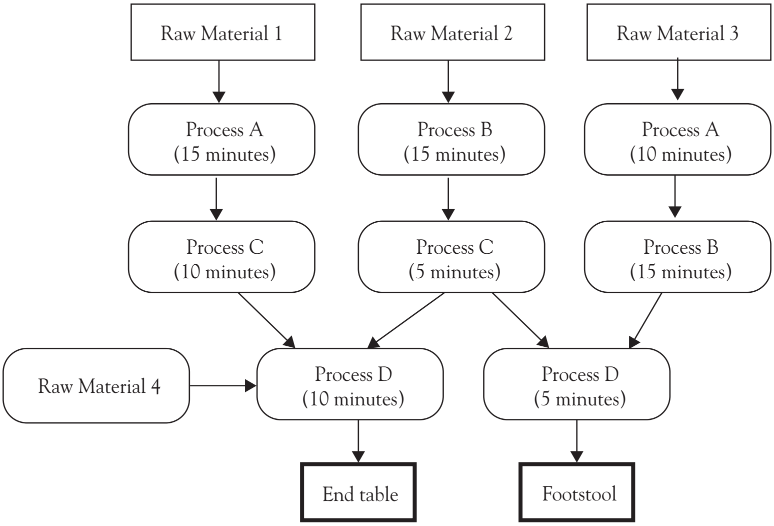

Figure 9.1 Diagram of production process

Table 9.1 Identify constrained resource

Resource (80 hours of each)	Time per footstool (minutes)	Time per end table (minutes)	Maximum ET possible	Maximum FS possible
A	15	10	320	480
B	15	30	320	160
C	15	5	320	960
D	10	5	480	960

With respect to ET, A, B, and C are equally constraining, limiting production to 320 ET; D has the capacity to do more. For the FS, B is the constraint, limiting production to 160 FS, while A, C, and D could produce more. Note that all four resources are needed to produce a product; so output is limited by the most constrained resource. In this situation, *B is the constraint.*

Comment: Here we identified the constraint, thus satisfying Step 1. Process B turned out to be the constraint, the step in the production process that limited total output.

Does Enough Capacity Exist to Meet the Supervisor's Schedule? No. Production of 200 ET and 100 FS requires 100 hours (6,000 minutes) of resource B, and we have only 80 hours. The 6,000 minutes of resource B needed is calculated as follows.

200 ET at 15 minutes	3,000 minutes
100 FS at 30 minutes	3,000 minutes
	6,000 minutes or 100 hours

Comment: There was not enough time in process B to produce 200 ET and 100 FS. Although processes A, C, and D had sufficient capacity (time), the budgeted output could not be completed and sold (throughput) without the work required in process B. Full output of both products required 100 hours of B, and Walden has only 80. Thus, the supervisor must decide on the mix of products, as full output of both products was impossible under current conditions.

A Tentative Production Plan Based on Product Profitability One way to select a production plan in the face of a constraint is to emphasize the production of the most profitable product. Thus, we first calculate the per-unit profitability of each product by conventional accounting means (see Table 9.2).

This analysis indicates that FS are clearly the more profitable product; so the tentative production plan is to maximize the output of FS (100).

Table 9.2 Product profitability

	ET ($)	FS ($)
Revenue per unit	90.00	100.00
Materials per unit	(44.00)	(38.00)
Contribution margin, or throughput	46.00	62.00
Labor: $15/hour × (55/60)	(13.75)	(12.50)
Overhead: $20*/hour × (55/60)	(18.33)	(18.33)
Per-unit profit	*13.92*	*31.17*

*Labor and overhead amount to $11,200 per week, of which labor is $15 per hour for 320 hours, or $4,800 in total. Subtracting $4,800 from $11,200 leaves $6,400 for overhead. If overhead is assigned on a per-hour basis (a common method), then the overhead rate is $6,400/320 hours, or $20 per labor hour.

This output requires 50 hours of Department B, leaving 30 hours for the production of ET, enough for 120 ET to be produced. Thus, the production plan is 120 ET and 100 FS.

Comment: The first pass at selecting how much of each product to produce was based on determining which product was more profitable, using conventional accounting. FS were clearly the more profitable product; so the production plan is to produce 100 FS (the maximum demand) and 120 ET. This decision took account of the constraint in process B, by having a total production that was achievable in the 80 hours of B available. But, as will be seen, it did not assure that we had yet identified the best use of B, even though we were maximizing what appeared to be the more profitable product.

What Is the Expected Profit from This Plan?

120 ET at \$90 − \$44 = 120 × \$46	\$5,520
100 FS at \$100 − \$38 = 100 × \$62	\$6,200
Total	\$11,720
Operating costs	(\$11,200)
Net profit	\$520

Comment: The profit outcome from the initial production plan (100 FS and 120 ET) is a weekly profit of \$520, far less than the original \$4,200!

Is There a Better Plan? To get the best outcome, we should maximize the throughput (*T*) value of the constrained resource, B. We can calculate B's throughput per minute:

If B makes ET, *T* = \$46 and 15 minutes are needed per unit:
\$46T/15 minutes = \$3.066T per minute

If B makes FS, *T* = \$62 and 30 minutes are needed per unit:
\$62T/30 minutes = \$2.067T per minute

B's time is more valuable when making ET, and the new production plan should be to maximize the output of ET (200). This output requires

50 hours of Department B, leaving 30 hours for the production of FS, and 60 FS could be produced. The revised production plan is 200 ET and 60 FS.

Comment: We introduce a new metric, the *throughput value per unit of the constrained resource*. It is a reasonable answer to the question of how to get the most out of the constraint (Step 2). FS had a throughput value of $62 ($100 selling price minus $38 material cost), and we needed 30 minutes of B to produce one footstool. B generates throughput at the rate of $2.067 per minute ($62/30 minutes) when producing FS. ET had a throughput value of only $46, but each table needs only 15 minutes of process B; so B generates a throughput value of $3.066 per minute ($46/15 minutes) when producing ET. Thus, producing ET is a better use of the constrained resource than producing FS, which suggests a production plan that maximizes end-table production. This conclusion led to a new plan of producing 200 ET (the maximum demand) and 50 FS, again fully utilizing B's time.

What Is the Expected Profit from the Revised Plan?

200 ET at $90 − $44 = 200 × $46	$9,200
60 FS at $100 − $38 = 60 × $62	$3,720
Total	$12,920
Operating costs	($11,200)
Net profit	$1,720

Comment: The revised plan yields a profit of $1,720, compared to $520 for the prior plan, or a $1,200 profit improvement. This analysis suggests that, in the face of constraints, one should make decisions by *maximizing the throughput value of the constraint.*

The Intern's Proposal The proposal is to buy a piece of equipment for $10,000 that would reduce B's process time (for both functions that B performs) from 15 minutes to 14 minutes, and would increase C's time to process RM2 from 5 minutes to 7 minutes. B is currently able to process 200 ET and 60 FS in the 80 available hours (4,800 available minutes). This change would reduce B's time from 15 to 14 minutes for ET and from 30 to 28 minutes for FS.

200 ET at 14 minutes	2,800 minutes
60 FS at 28 minutes	1,680 minutes
Total	4,480 minutes

Current production would thus require only 4,480 minutes of B's time. The 320 minutes that are freed up by this change could be used to produce additional FS. In 320 minutes, B could produce 11.4 (11 in whole numbers) more FS per week. This added production would generate an additional throughput of $682 (= 11 × $62) per week. The additional time required for C is costless since C has enough excess capacity to handle the additional time required.

Comment: This part of the scenario illustrates Step 4, attempting to relax or *elevate* the constraint. The proposal saves a minute in process B at a cost of two more minutes in process C. Although increasing total production time may initially seem unappealing, a closer look shows that Walden is saving time on the constraint (B)—which will permit an increase in throughput—while the added time on process C doesn't matter since Walden is not fully utilizing that resource and thus has plenty of excess capacity. Assuming that Walden saves a minute in both of B's actions (shaping the 12 × 16 × 1 maple, which applies to both products, and notching the pine legs), then the earlier production plan of 200 ET and 60 FS, which had used all 4,800 minutes of B's time before, would now require only 4,480 minutes, freeing up 320 minutes of B's time, which can be used to produce more FS (Walden is already producing the maximum demand of ET). With 320 minutes now available, at 28 minutes per footstool, Walden could produce 11.4 more per week. Rounding down to 11 additional FS, at a $62 throughput value each, would generate an additional $682 profit weekly, which would pay for the $10,000 new machine in about 15 weeks. Thus, the proposed change, even though requiring a $10,000 investment and expanding the total processing time, would be beneficial.

Conclusion

The theory of constraints has much to offer for revenue management. Throughput, or net revenue, is the major metric in a TOC system, and most decisions emphasize the ability to generate more throughput and to do so efficiently. A strategy of maximizing throughput without increasing operational expense or inventory is a strategy of profitable revenue growth. Further, the notion of maximizing the throughput of constrained resources strengthens the link between revenue management and capacity, as developed in the preceding chapter. Although analyzing constraints and applying TOC concepts require a thorough and detailed analysis, improved management of revenues and increases in profit can result.