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1. Objectives
2. Terminology
3. Concepts
4. Practices and Techniques
5. Management of Accounting Activities

Statement on Management Accounting

Statement No. 4HH

June 1999

Theory of Constraints (TOC)

Management System Fundamentals

Institute of Management Accountants

Arthur Andersen LLP

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## I. RATIONALE

- 1 The theory of constraints (TOC) is a systems-management philosophy developed by Eliyahu M. Goldratt in the early 1980s. The fundamental thesis of TOC is that constraints establish the limits of performance for any system. Most organizations contain only a few core constraints. TOC advocates suggest that managers should focus on effectively managing the capacity and capability of these constraints if they are to improve the performance of their organization.
- 2 Once considered simply a production-scheduling technique, TOC has broad applications in diverse organizational settings. For example, TOC has proved to be a milestone concept leading to process improvement in organizations such as Avery Dennison, Bethlehem Steel, General Motors, National Semiconductor, United Airlines, Boeing, ITT, and Procter and Gamble. Similarly, the United States Air Force Logistics Command has adopted constraint management concepts to improve the performance of aircraft repair depots, while the United States Navy has implemented TOC concepts in its Transportation Corps.
- 3 TOC challenges managers to rethink some of their fundamental assumptions about how to achieve the goals of their organizations, about what they consider productive actions, and about the real purpose of cost management. Emphasizing the need to maximize the throughput—revenues earned through sales—TOC focuses on understanding and managing the constraints that stand between an organization and the attainment of its goals. Once the constraints are identified, TOC subordinates all the nonconstraining resources of the organization to the needs of its core constraints. The result is optimization of the total system of resources.
- 4 As organizations and the financial practitioners who support them continue to learn which questions to ask, as well as which information best addresses these concerns, the need to add new models to the information toolkit grows. TOC is a vital part of this expanded toolkit, providing unique insights and focus into the ongoing

challenges of identifying the products and services that will maximize customer value-added and organizational profitability.

## II. SCOPE

- 5 This Statement on Management Accounting (SMA) has been written to facilitate the process of designing a TOC management system that is compatible with other key cost management initiatives. The methods and principles presented in this SMA supplement the research project titled *The Theory of Constraints and Its Implications for Management Accounting*, sponsored by the Institute of Management Accountants' Foundation for Applied Research (FAR).
- 6 The focus of this publication is on those TOC techniques dealing with logistics/scheduling, market segmentation, and performance measurement. It is beyond the scope of this guideline to discuss the TOC generic problem-solving techniques referred to as the "Thinking Process" and "Project Management" since these are the least researched and least visible of the TOC concepts for finance and operations management. The concepts discussed in this document apply to:
  - large and small organizations; and
  - enterprises in all business sectors.
- 7 The information in this SMA will help financial professionals and others to:
  - comprehend the underlying principles of TOC;
  - understand the various elements of TOC management systems;
  - determine the uses and benefits of TOC for their own organizations;
  - compare TOC with different cost management approaches;
  - design a throughput accounting system;
  - understand the difference between throughput accounting and constraints accounting;
  - appreciate their roles and responsibilities in TOC management systems; and

- broaden employee awareness and obtain their buy-in for TOC management systems.
- 8 While this SMA cannot provide comprehensive knowledge of these concepts, the information contained within this document serves as a starting point in the exploration and implementation of TOC. The discussion will illustrate core ideas and provide finance and operations professionals with a basic understanding of TOC and its applicability to their organization and its unique challenges.

### III. KEY PRINCIPLES UNDERLYING TOC

- 9 Several key principles underlie TOC and, according to Goldratt, converge to make fertile ground for TOC. A few of these key concepts are worth emphasizing because of their significance for the management approach used in adopting organizations. The principles include:
- *Processes/organizations as chains.* This is crucial to TOC. If processes and organizations function as chains or flows, the weakest links can be found and strengthened. The linkages in question can be between the different steps or activities in a process or between diverse organizations within a supply chain.
  - *Local versus system optima.* Because of interdependence and variation, the optimum performance of a system as a whole is not the same as the sum of all the local optima. (Local optima are calculated measures for functional areas within an organization.) In other words, an organization that maximizes the output of every machine will not perform as well as one that ensures optimization of the flow of materials and value created through its linked set of activities.
  - *Cause and effect.* All systems operate in an environment of cause and effect. One event causes another to happen. This cause-and-effect relationship can be very complex, especially in complex systems. Capturing the essence of cause and effect within the system and identifying measurements that emulate these relationships are the keys to optimizing system performance.

- *Physical versus policy constraints.* Most of the constraints faced in systems originate from policies, not physical things. Physical constraints, such as the number of nurses in a hospital or the number of production machines in a factory, can be objectively identified and dealt with. Policy constraints (e.g., behavior patterns, attitudes, lack of information, and assumptions) are potentially more damaging than physical constraints, yet are much more difficult to identify and deal with. The belief that producing in large batches is optimal is an example of a policy constraint that can make implementing TOC or related advanced manufacturing approaches difficult.
- *Total system impact.* All organizations are systems made up of interdependent activities, each with its own level and type of variability. In order to optimize performance, management needs to understand and focus on the total system impact of a decision or event, not just on its local or immediate effects.

#### IV. DEFINING TOC

- 10 The theory of constraints (TOC) is a concept that emphasizes the role of constraints in limiting the performance of an organization. TOC drives managers to attack constraints in order to reach their primary goal—to make money. Elegant in concept and design, TOC focuses management’s attention on the factors that impede system performance.
- 11 TOC emphasizes the optimization of performance within the defined set of constraints of the existing processes and product offerings. TOC provides an action framework that combines the activities of managers around a few highly visible system elements.
- 12 TOC represents a tremendous change in management, focus, and direction. It is a transition shaped by several fundamental concepts that can be used to build a profitable foundation for any organization. These concepts include:
  - a new measuring system;
  - a process of continuous process improvement;

- a fundamental decision process focusing on global rather than local issues;
  - a new method for analyzing the relationships between resources and processes and determining where to focus the company's efforts;
  - new methods for analyzing policy problems to arrive at simpler solutions; and
  - a new management approach for providing strategic and tactical direction.
- 13 TOC incorporates the idea that the goal or mission of an organization is the reason the organization exists. Only the owners of the organization can determine its goal or mission. For a publicly held, "for-profit" organization, the goal would be to maximize profitability today and tomorrow, because that is why the shareholders have invested.
- 14 TOC management systems normally consist of the following elements:
- *Logistics/scheduling.* The scheduling methodologies of drum-buffer-rope, buffer management, V-A-T logical structures analysis, the five-step focusing process, and supply chain management are used to establish and control the flow of materials to the final product within a TOC environment.
  - *Performance measurement.* Built around the core metrics of throughput, inventory, and operating expense, TOC develops and uses a series of measurements that directly link financial performance with nonfinancial performance.
  - *Problem-solving/thinking process.* This process consists of effect-cause-effect (ECE) diagramming and its components, the ECE audit process, and the "evaporating cloud" methodology for conflict resolution. The essence of ECE is the scientific method, which suggests that if a secondary confirming effect is found when a cause or event occurs, then it can be argued that the cause truly leads to the hypothesized effect. In other words, two or more occurrences of the same cause-and-effect relationship

are needed to uncover the primary cause of the majority of the detected problems within the system.

- *Project management.* The standard concepts in project scheduling and management have been the critical path method (CPM) and the program evaluation review technique (PERT). TOC's critical chain concept removes the implicit assumption of infinite capacity from the project management domain, just as the TOC drum-buffer-rope technique removes it from the factory floor domain.
- *Market segmentation.* While TOC originated as a production scheduling technique, it has evolved into much more. TOC offers important insights to all managers, and especially to cost managers, in the areas of product mix and product pricing decisions.

15 These elements are brought together in [Exhibit 1](#), resulting in a schematic of the TOC management system.

## V. USES AND BENEFITS OF TOC

16 TOC has broad applications in organizations. As such, its benefits cross multiple boundaries and functions, resulting in uses and benefits including:

- decreased production lead times;
- improved quality of products and services;
- dramatic increases in profitability;
- reduced inventory levels;
- reduced bottlenecks;
- management of constraints;
- curbing of statistical fluctuations;
- improved competitive position;
- facilitation of strategic marketing and operational decisions;
- introduction of the marginal pricing concept; and
- application of continuous improvement at the supply chain level.



- 17 TOC has broad applications in manufacturing organizations, but it can also be used effectively to improve performance in areas outside of manufacturing, such as marketing and administration. TOC can be used in conjunction with other management techniques such as total quality management (TQM) and just-in-time (JIT) to provide a comprehensive, linked set of techniques that emphasize continuous improvement in all areas of operation. TOC has also been applied at the supply chain level to coordinate the activities of upstream and downstream trading partners.
- 18 ITT's Neil Gallagher, president and general manager of the Night Vision Division and an expert advocate of TQM methods within ITT's Defense and Electronics group, pioneered many of the ways TOC methods are used to focus TQM techniques on growth in sales and profitability. His team at the Night Vision Division used TOC-guided TQM to double yields, triple throughput, and reduce back-shop cycle time by half.
- 19 One firm, Ketema A & E, was able to focus process engineering changes and improvements in order to evaluate the incoming requests, as to the effects that taking on the business would have on the factory's constraints and, therefore, on the profitability of the entire organization. Sometimes large orders at lower prices were discouraged, given the impact on other business and needed investments in new capacity. TOC helped guide this process toward greater profitability and improved cash flow.
- 20 As these applications of TOC suggest, the range of improvements that come from applying systems thinking to the management of an organization and its key processes are not limited to the shop floor. Providing a means to balance the activities of the organization, from the initial customer contacts in marketing through downstream support and service, TOC ensures that the highest priority is placed on reducing the constraints that inhibit the rapid response to customer requests. Integrated with other data in the information system, such as activity-based costs, TOC can help an organization leverage its core capabilities to optimize financial performance. Making these linkages is one of the key roles played by management accounting in TOC implementation and utilization.

## VI. THE ROLE OF MANAGEMENT ACCOUNTING

21 The financial professional, playing a pivotal role in TOC implementation, uses management accounting to focus on identifying, analyzing, and reporting key events and opportunities affecting the organization. Emphasizing the development and maintenance of core management information sources within an organization, management accounting serves as the basis for integrating the diverse sources of data available to decision makers. Within TOC, the role of management accounting includes the following activities:

- provide economic estimates of throughput, operational expense, and inventory;
- accumulate and integrate data from TOC, total quality management, and related management models to ensure consistency in the reporting system;
- verify constraint identification;
- provide capacity cost estimates and support for investment analysis of potential additions to capacity;
- explain the various assumptions underlying differences from other strategic or tactical analyses;
- work with operating managers to identify solutions for easing constraints and their impact;
- develop and sustain the activity-based cost management system to complement the information provided and required by TOC;
- work to develop a comprehensive knowledge of incremental cost patterns and underlying cost structures to ensure that ongoing TOC decisions incorporate the impact on step-fixed and semivariable costs throughout the organization;
- provide throughput contribution data and identification of the relevant constraint for all decisions;
- identify direct linkages between throughput and operational expenses;
- report on the impact of constraints; and
- ensure that the finance function does not become the constraint.

- 22 One of the key roles played by the finance function in a TOC setting is the development of the comprehensive cost structure information needed to identify the impact of constraints and changes in operations on the step-fixed costs of the organization. As the percentage of fixed and step-fixed costs in an organization's cost structure increases, it becomes more important than ever to understand when new costs will be incurred. It is also critical to know what the capacity of each increment of resource cost is, as well as how to best design processes and systems to minimize permanently idle or wasted resources. The finance professional is the individual with the greatest expertise in understanding relevant and incremental cost principles. These cost principles are assumed and required knowledge for TOC to operate effectively.
  
- 23 As in many situations that occur within an organization, it falls to the finance function to ensure that information is collected consistently, objectively, and in a format compatible with other data sources. This does not mean that TOC or any other management system should be required to provide traditional standard cost data. Instead, it becomes imperative that finance professionals develop new forms of cost information to ensure that this crucial data source is designed and maintained to complement the needs of managers throughout the organization. Shifts in the nature and format of financial reporting are necessary if the financial reporting system is to retain its relevance and value. Retaining relevance in a TOC environment begins with understanding the TOC methodology and its information requirements.

VII. TOC LOGISTICS/SCHEDULING, MARKET SEGMENTATION, AND PERFORMANCE MEASUREMENT TECHNIQUES

Logistics/Scheduling

- 24 The logistics and scheduling aspects of TOC emphasize the synchronization of the flow of materials and services from the initial contact with customers through the downstream support and service activities.

The following elements form the foundation for implementing the logistics, or flow-oriented, concepts of TOC management:

- five-step focusing process;
- V-A-T logical structure analysis;
- drum-buffer-rope scheduling method;
- buffer management; and
- supply chain management.

### *The Five-Step Focusing Process*

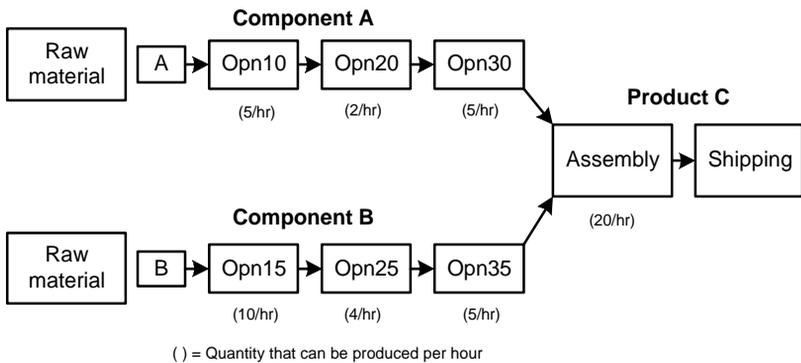
- 25 At the heart of TOC lies a five-step procedure that enables managers to plan the overall process and focus attention on the resources with the greatest potential to be affected by changes to the system. Reflecting the key underlying principle of TOC—namely, that the performance of a system is limited by its constraints—these five steps create a framework for TOC implementation and utilization.
- 26 The five steps in the TOC focusing process are:
- Step 1. *Identify* the system's constraints. The first step is to identify the constraint in the system that limits throughput or progress toward the goal.
  - Step 2. *Decide* how to *exploit* the constraint(s). Decide on a plan for the primary constraint that best supports the system's goal. This requires taking advantage of the existing capacity at the constraint, which is often wasted by making and selling the wrong products, and by improper policies and procedures for scheduling and controlling the constraint.
  - Step 3. *Subordinate* everything else to the above decisions. Alter or manage the system's policies, processes, and/or other resources to support the above decisions. Management directs its efforts toward improving the performance of the constraining task or activity and any other task or activity that directly affects the constraining task or activity.
  - Step 4. *Elevate* the constraint(s). Add capacity or otherwise change the status of the original resources as the dominating primary constraint. In this step, additional capacity is obtained

that will increase (elevate) the overall output of the constraining task or activity. This differs from step 2 in that the added output comes from additional purchased capacity, such as buying a second machine, tool, or implementing new technology.

- Step 5. *Return* to step 1. Don't let inertia become the new constraint—go back to step 1, but do not allow previous decisions made in steps 2 to 4 to become constraints. As a result of the focusing process, the improvement of the original constraining task or activity may cause a different task to become a constraining task or activity. Inertia could blind management to additional steps necessary to improve the system's output now limited by a new constraint.
- 27 The five focusing steps enable management to remain focused on what is really important in an organization—the system's constraint(s). Why is the constraint the most important target? Obviously, it is the pacesetter for the entire system. No matter how fast the other components can do their job, the system cannot produce at a rate faster than its slowest component. The chain is no stronger than its weakest link. But it goes well beyond this concept in practice.
- 28 The first step is to identify the constraint in the system that limits throughput. TOC emphasizes the importance of constraints over the importance of product costs, noting that growth comes from improving the flow of materials through productive processes rather than through piecemeal cost-reduction efforts in any one area of the system.
- 29 Constraints can be classified in one of the following categories: behavioral, managerial, capacity, market, and logistical, each having its own impact on the smooth operation of the organization. For example, behavioral constraints are those behaviors and work habits exhibited by employees that result in poor performance from a global perspective. Managerial constraints are erroneous management strategies, policies, and decision mechanisms. Logistical constraints involve limitations placed on the system by the planning and control systems. (The different types of constraints are discussed in greater detail in the appendix of this SMA.)

- 30 Constraints interact to reduce throughput. For instance, poor scheduling of what would in reality be a nonconstrained resource can, over time, turn it into a real constraint, one that has a negative impact on the actual system constraint. Batching can also create interactive problems, as it places artificial buffers, or lumpy volumes, into the system that can clog up the throughput or starve the bottleneck. The key is to understand the real and created constraints that exist throughout the system and to identify how they are affecting the total throughput of the organization. Exhibit 2 illustrates a hypothetical capacity constraint in a manufacturing setting.

Exhibit 2. Identifying the System Constraint



Source: Adapted from Cox and Spencer, 1998: 9.

- 31 Product C is assembled from two components, A and B. The components start as raw materials A and B, respectively, and each goes through three different operations at different work centers. Raw material A goes through operations (opn) 10, 20, and 30, while raw material B goes through operations 15, 25, and 35.
- 32 Components cannot skip an operation and then go back, nor can they be produced at any other work center. Each operation requires a certain amount of production time at each work center, and because different physical operations are performed at different work centers,

the times and rates vary from one operation to another. Using raw material A, operation 10 can be performed at a rate of five units per hour; operation 20 can be performed at a rate of two units per hour; and operation 30 can be performed at a rate of five units per hour. Raw material B is used at a rate of 10 units per hour at operation 15, its first step; at a rate of four units per hour at operation 25, its second step; and at a rate of five units per hour at operation 35, its final step.

- 33 Assembly of components A and B into product C is rather simple and takes only three minutes, at a production rate of 20 units per hour. However, the two components that make up the assembly take much longer to manufacture. Component B's first operation, 15, is completed in six minutes at a rate of 10 units per hour. But all the other operations take longer. Operations 10 and 30 of component A and operation 35 of component B each take 12 minutes to produce one unit. The heart of managing constraints is now becoming apparent.
- 34 The slowest operation in this case, operation 20, is used to make component A and determines the output of the entire system. Operation 20 takes 30 minutes per unit; since each product C takes both an A and a B component, no more than two units per hour can be manufactured even though, theoretically, many more units can be assembled within the same timeframe. The output of the slowest work center (weakest link) determines the output of the entire system.
- 35 Exploiting the constraint is one way that its effects on the system can be lessened or eliminated. This can be done in any number of ways. Specifically, demand can be shifted off of the constrained resource by deploying other, albeit less efficient, machines wherever possible. Second, the impact of the constraint can be lessened by "breaking batches" or reducing internal setup time (e.g., when the machine is down) to increase the utilization of the machine or activity. A third approach is placing quality control in front of the constrained resource, ensuring that no defective product is allowed to waste critical time on the bottleneck. Whether offloaded, streamlined, or optimized, the capacity-constrained resource (CCR) remains the focus of TOC efforts to improve throughput and profitability.

- 36 Having successfully identified the system constraint, and having used one of the noted approaches or a similar process improvement technique to optimize the throughput of the system, it becomes critical to ensure that all other activities are driven by or subordinated to the decisions made in step two. In almost all situations, this will require de-tuning parts of the system and accepting idle time as a way of life in some areas. This is a very difficult idea for most managers to accept, especially those accustomed to—and perhaps rewarded for—individual process efficiencies (that is, suboptimization).
- 37 Measurements play the key role in this subordination. They make different parts of the system, which may not be key to optimizing throughput, visible to managers. Changing measurements to emphasize the constraint, therefore, is a critical part of the five-step focusing effort.
- 38 At this point organizations have a decision to make. Did the first three steps break the constraint (that is, the originally identified constraint no longer limits the system's performance)? Often the exploitation and subordination steps are enough. If so, organizations can go on to step 5. If not, the next step must be to elevate the constraint.
- 39 Since the original constraint is still limiting system performance, despite an organization's best efforts to make it as efficient as possible, the only remaining course of action is to increase the capacity of the constrained part of the process and to continue doing so until the constraint is really broken. Elevating may mean buying another piece of equipment (a capital investment) or contracting out part of the constraint's load. Or it might be as simple as instituting limited overtime or adding a second shift.
- 40 The distinction between exploiting and elevating is simply that exploiting means changing how an organization uses the constraint without spending more money, and elevating means investing more money to increase the constrained resource's capacity. If the idea involves spending more money than the organization is currently

spending to make money, then the organization is elevating, not exploiting. But why spend money if an organization does not have to? Clearly it doesn't make much sense for an organization to elevate until it is sure that it is already exploiting the constraint to its fullest potential.

- 41 The final step, which entails returning to step 1 of the focusing process, is designed to build the concept of continuous improvement into TOC. Without this last step, an organization might stop its efforts once the constraints have been optimized. In TOC, the journey toward superior system performance never ends. As one bottleneck is managed, attention turns to finding the next activity or problem that inhibits the organization's ability to make money by creating value for its customers.
- 42 Many organizations, including several large semiconductor manufacturers, have used this five-step process to uncover large amounts of hidden production capacity in their factories. Each time the primary constraint is identified and exploited, throughput is increased and non-value-added activity is removed. The non-value-added activity is removed first from the constraint directly but also from all other resources and processes that affect the constraint indirectly. This allows processes to be improved with surgical precision and with high bottom-line impact for the time spent in the improvement process.
- 43 For example, TOC has been used to recover over \$500,000,000 of hidden capacity in Texas Instrument's (TI) semiconductor operations. The company was able to set aside planned capital expenditures for equipment the industry called a "new front end" because the "new" capacity was available for use right away (versus after a years-long procurement and construction cycle). TI was able to complete major new product introduction cycles more quickly, which provided powerful advantages and strategic positioning related to time-to-market performance.
- 44 While the five-step focusing process is the most commonly described and applied element of TOC, a number of other approaches and

techniques can be used to improve system performance, including V-A-T logical product structure analysis.

### *V-A-T Logical Product Structure Analysis*

- 45 Because of the traditional way of organizing a business, organizations tend to view a business as either product centered, comprising marketing and sales, for example, or production centered, comprising engineers and planners. In fact, the development of computer-based production planning methods such as materials requirement planning (MRP) reinforced this functional view of a business. However, this view often leads to good managers making bad decisions.
- 46 The V-A-T analysis is an approach that breaks down the traditional barriers and views the organization as an interaction of both products and processes. By seeing the organization in a systems view, three general categories of production structures or shapes emerge; each structure requirement is a somewhat different approach to management planning and control. These interactions have been found to take on one of three primary product or product-line structures: the V shape, the A shape, and the T shape.
- 47 Of these, the T shape is most common. It describes settings where a number of common parts or related products flow across a limited, shared set of workstations or activities. The T product structure offers a number of features and options from which to choose in defining the end product. For example, automobiles, VCRs, pens and pencils, notebooks, and computer configurations represent product lines for which similar assemblies and subassemblies or slight product variations (in color, size, etc.) are used to create a wide variety of finished products. Shared resources can rapidly become constraints on the throughput of the system.
- 48 Within T structures, the most common bottleneck is finishing or packaging. A second concern in the T structure is the identification of the optimal “gating”<sup>1</sup> activity, which can be used to control the

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<sup>1</sup> Gating activities represent the first operation in the system.

release of orders into the system. The gating activity should ensure that the number of orders released does not exceed the capacity of the system constraint.

- 49 The second most common structure found in systems is the V shape. The term “V structure” represents a fixed-flow (identical routings for all products in the family) product structure in which product variation occurs. Characteristic of many process environments, these structures rely on one or a small number of materials to provide a wide variety of unique products and services to the market. Commonly known as divergent processes, there is no turning back and no rerouting possible to overcome a constraint in a V structure.
- 50 In contrast to a T structure, in which the convergent activity dominates management’s attention, it is the divergent operation that places the limits on the flexibility of management. For instance, once a steak dinner has been prepared medium, it can no longer be offered to a customer requesting a medium-rare or rare steak. According to TOC, in V structures buffers must be created before the bottleneck, as well as after it, to ensure that the minimal amount of disruption to the system occurs. Departmental efficiencies cannot be used to measure performance in divergent systems; scheduling that incorporates the constraint schedule and final customer order priorities and quantities drives decision making and evaluation.
- 51 Finally, the term “A structure” represents a product structure in which a number of raw materials, parts, subassemblies, and assemblies are processed and assembled into a few finished parts. The A structure uses a wide variety of resources to supply a broad range of products and services. Similar to a T structure, convergence of activities and subassemblies does occur in an A structure. However, within an A structure a significant number of activities also take place after convergence.
- 52 Characterized by the largest number of potential routings and variety, A structures present the greatest challenge to management. For

instance, the constraining resource can be expected to float in an A structure, as mix shifts and the demand on key areas changes based on the unique features of current production. The constraint may be a particular skill set in limited supply in the workforce, or a piece of machinery that is used by almost all orders.

- 53 Generally existing in the fabrication area in an A structure, constraints must be managed through customer order prioritization and well-defined schedules. Controlling the constraint, choosing a gating operation, and ensuring that unconstrained resources do not impair throughput are the greatest challenge in the dynamic operations characterizing an A structure.
- 54 By using the V-A-T logical structure analysis, by viewing a production process as a system, and by planning and controlling material flows using the control points, significant improvements in production processes can be made. The management of a factory is not a uniform set of activities but should be a function of the overall process. Different factories have different processes and require different management. Planning and controlling using the control points and buffer management give managers the ability to better focus management improvement activities. The control points in each logical structure are identified in [Exhibit 3](#).
- 55 As illustrated in the exhibit, V-A-T logical structure analysis helps management see key constraints and identify the optimal throughput for the system given its structure. Options for elevating the constraint and improving throughput are based on the defined structure of the system and the complexity of the underlying flow. Emphasizing the identification and management of the gating operation, as well as the use of time and space buffers to smooth the flow of product or services through the system, V-A-T-based analysis places a framework around constraint analysis and management. This framework provides for the effective application of TOC logic within a broad range of potential systems and situations.

### Exhibit 3: V-A-T Logical Structure Control Points

V-A-T structure		A-structure			T-structure		
Code	Function	Code	Code	Code	Code	Code	Code
0310	Finished products	0340					
0320		0330					
0330		0350					
0340		0360					
0350		0370					
0360		0380					
0370		0390					
0380		0400					
0390		0410					
0400		0420					
0410		0430					
0420		0440					
0430		0450					
0440		0460					
0450		0470					
0460		0480					
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### *Drum-Buffer-Rope Scheduling Method*

- 56 All manufacturing plants have dependent events and statistical fluctuations. The challenge is to manage these events and fluctuations so that the organization achieves its goal. The emphasis in drum-buffer-rope scheduling (DBR) is the incorporation of the inevitable dependent events and statistical fluctuations within any system in the development of a scheduling approach.
- 57 The DBR methodology is a technique for developing a smooth, obtainable schedule for the plant and for maximizing and managing the productivity of a manufacturing facility from a global, not a local, perspective. It differs from other manufacturing techniques in that it concentrates on determining the relationships among resources in resolving conflicts to create a smooth flow of product and is applicable to all types of processes whether they are repetitive, process, or job shop. Drum-buffer-rope also provides an improved method of focusing protection so that the impact of disturbances on smooth production flow can be minimized.
- 58 The DBR process was designed as a means of implementing the five-step process of continuous profit improvement and therefore represents a tremendous leap forward in managing the shop floor from a profitability perspective. It is distinguished by representing how a factory should be scheduled based on TOC.
- 59 The DBR methodology consists of three elements:
- the drum
  - the buffer; and
  - the rope.

#### *The drum*

- 60 The drum is the schedule for the system's constraint(s) and represents a portion of the exploitation phase of the five-step improvement process. It is used to maximize the available time of the constraint and to create the master production schedule (MPS). Like the bass drum in a marching band, it is the drumbeat of the manufacturing facility. All other resources produce in synchronization to the constraint's schedule.

- 61 In order to schedule the constraint, an attempt is made to place the start and stop times for each order on a time line so that two conditions are met:
- enough protection is available to ensure that each sales order due date is met; and
  - no conflicts exist between orders attempting to occupy the same space at the same time.
- 62 While the second condition must be met to create a valid schedule, the first condition is subject to the results of the second. If time is not available, sales orders will be pushed out and due dates will not be met.
- 63 Additional considerations arise when secondary constraints begin to appear. These are resources that have been scheduled to near-capacity levels, and because of this, will have trouble meeting the demands of the primary constraint schedule. After the primary constraint has been scheduled, resources that are loaded to near-constraint levels must be protected to ensure that the schedule for the primary constraint can be met.
- 64 Secondary constraint schedules must be built so that whatever time is available at the secondary constraints can be maximized. However, the secondary constraint schedule must consider the schedule already established for the constraint. So, when building the secondary constraint, an additional consideration must be added; there must be no conflicts between the primary and secondary constraint schedules.
- 65 Once the primary schedule has been set, the secondary schedule must attempt to schedule around it. If unsuccessful, a reschedule of the primary constraint must take place.

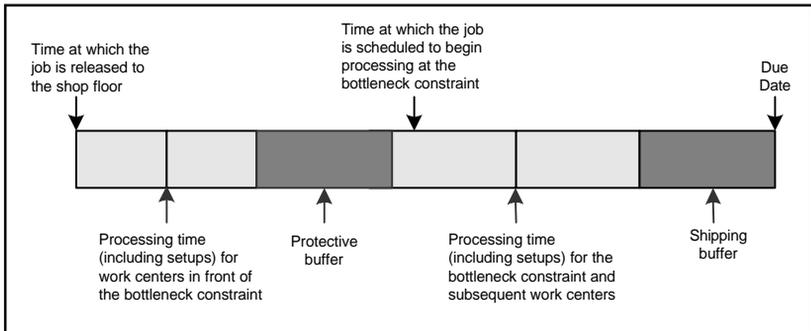
*The buffer*

- 66 The buffer is a time mechanism used to allow for those things that will go wrong, and it determines the lead time for products from the gating operations. The buffer is equal to the processing time plus the setup time plus an estimate of the aggregated amount of protective

time required to ensure that the product will get to the buffer origin when needed. Three areas (buffer origins) typically require protection, as illustrated in Exhibit 4:

- shipping to ensure that parts are delivered to the customer on time;
- the constraint to ensure maximum utilization of resource time; and
- those assembly operations in which one leg of the process is fed by a constraint and the other is fed by nonconstraints so that parts that have been processed at the constraint will not wait in the assembly operation before parts from other, nonconstrained resources arrive.

Exhibit 4. Buffers in a DBR Scheduling System



Source: Noreen et al., 1995: 33.

### *The rope*

- 67 The rope is the synchronization mechanism for the other resources and consists of the release schedule for all gating operations. Technically the rope is equal to the constraint schedule date minus the buffer time. The release of material determines the timing for parts being processed on the nonconstraint resources.
- 68 Operating under DBR requires a culture change. The culture change required in most plants to operate DBR has to do with realizing that

by definition, the nonconstraint operations have a greater capacity and therefore will have some nonproductive time during the workday. This is good. If this is not the case, the plant is “too balanced” and will not operate effectively using the DBR method. In other words, the plant should be unbalanced with greater capacity at all operations except at the designed constraint. Then, the rest of the plant can be properly scheduled and raw materials fed into the process based on that schedule.

69 If the plant is balanced, the constraint will appear to move around during the day. To properly operate DBR, the plant must be unbalanced to the extent that the constraint is obvious and consistently located. Most important, a nonconstraint should never be fed with work just to keep it busy. That does not increase throughput and only serves to add unneeded work-in-progress (WIP) inventory.

70 In summary, the DBR methodology is a technique for developing a smooth, obtainable schedule for the plant and for maximizing and managing the productivity of a manufacturing facility from a global, not a local, perspective. DBR also provides an improved method of focusing protection, so that the impact of disturbances on smooth production flow can be minimized. For example, Valmont/ALS, a job-shop steel fabricator in Brenham, Texas, faced with mediocre inventory turns, increasing amounts of overtime, and a recession in the 80s, utilized DBR to better assist in the management of their inventory buffers. DBR provided production control with a detailed analysis of parts missing from the desired buffer and their current location and process time remaining. Improvements as a result of implementing the DBR method of operating included:

- the actual lead-time for certain product lines had been cut to half the assumed industry standard lead-time;
- due-date shipment performance had improved to the mid-to-upper 90 percent range;
- shipment levels increased to their highest level in the company's history, yet personnel were still near the low post-layoff levels; and

- return on equity was up and cash flow was 60 percent greater than the operating plan.

### *Buffer Management*

- 71 Buffer management is an integral part of TOC execution. Whether the buffer being managed is the constraint buffer, the shipping buffer, or the assembly buffer, the approach is the same.
- 72 Under TOC, buffer management forms the basis for shop floor control. Specifically, nonconstrained resources are scheduled to ensure that they are working on the right jobs, at the right times in the sequence, and in the right production batch quantities to meet the requirements of the constrained resource's schedule and related customer delivery needs.
- 73 Buffer management can serve as an early warning system. Strategic placement of buffers can be used to identify process problems prior to their emergence, as holes between the “drum” or gating operation's schedule attainment and that of the constrained resource become evident. The comparison of these two schedules allows the buffer manager to identify any upcoming shipments that may miss their prescheduled delivery times, giving opportunity to find ways to adjust production to avoid the potential problems.
- 74 Buffer managers make adjustments to the schedules for shipping and for the drum work center, because the drum schedule produced by the DBR scheduling process is the timetable that causes the factory to produce the most it can possible make, consistent with the priorities in the shipping schedule.
- 75 Buffer management worksheets, as illustrated in [Exhibit 5](#), can be utilized to facilitate quantitative analysis and to ensure uniformity in data collection. Whenever a part fails to reach the buffer origin prior to the beginning of the expedite zone,<sup>2</sup> it is expedited and the

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<sup>2</sup> Expedite zone—zone 1 of the buffer. The expedite zone is used to indicate when the absence of an order is threatening the exploitation of the constraint and to notify the buffer manager when to expedite parts.

cause and location of the delay are recorded, along with the degree of lateness incurred. The information is used in the Pareto analysis to determine what actions must be taken to reduce the amount of protection necessary.

Exhibit 5. Buffer Management Worksheet

Buffer origin: <u>Resource C</u>		Date: <u>10/25/91</u>		
Buffer length: <u>16 hrs</u>				
Name: <u>John Smith</u>		Zone 1		
<u>Location</u>	<u>Station</u>	<u>Cause of Delay</u>	<u>Arrival Required</u>	<u>Actual Arrival</u>
<u>R-1</u>	<u>123/30</u>	<u>Solder required</u>	<u>2:15</u>	<u>5:15</u>
<u>R-1</u>	<u>123/20</u>	<u>Keyway</u>	<u>3:30</u>	<u>3:45</u>
<u>R-2</u>	<u>121/30</u>	<u>Out of material</u>	<u>5:10</u>	<u>7:10</u>
<u>R-3</u>	<u>126/40</u>	<u>Rework required</u>	<u>1:30</u>	<u>2:30</u>
<u>R-1</u>	<u>131/20</u>	<u>Machine down</u>	<u>2:30</u>	<u>3:30</u>

Source: Adapted from Stein, 1997: 120.

- 76 The buffer origin designates the location of the buffer at a specific resource or at shipping. The buffer length gives the buffer manager an indication of the buffer length used at a particular operation so that an idea of the amount of protection given can be established.
- 77 Fine-tuning the amounts of protective time, capacity, and work-in-process buffers is called *dynamic buffering*. Using continuous improvement techniques, reductions in buffer sizes are made until problems appear. These adjustments do not need to be made in real time; Gantt and dependency charts can be deployed to analyze the system and identify its limits. Manufacturing resource planning (MRP) can also be used to conduct sensitivity analysis on the buffers.

## *Supply Chain Management*

- 78 TOC can be applied outside of the boundaries of the organization, reaching backward and forward in the supply chain to reduce inventories, improve throughput, and increase responsiveness to changing customer needs. Leveraging the concept of the primary constraint across the supply chain creates priorities and schedules that ensure that the system-wide limiting factors serve as the basis for the development of integrated scheduling and logistics planning and execution. These linkages can take the form of protective capacity or protective time or inventory buffers. The goal is to maximize the profitability of the entire system by ensuring that the system's constraint is used to pace the entire flow of materials and value from the beginning to the end of the production cycle. DBR scheduling, in other words, is applied across organizational boundaries to ensure that the constrained resources are used effectively.
- 79 Cross-organizational, intermediate- to long-term relationships are rapidly becoming a point of major improvements in value creation. The development of trading alliances is premised on the belief that leveraging the resources available throughout the supply chain is the key to superior performance. Though often stated in terms of maximizing the core competencies of the supply chain, it is just as critical that the process used to deliver the product/service bundle also be managed to ensure optimization. As organizational boundaries become more and more transparent and permeable, the linkage of both physical flows and policy/management approaches will be critical.
- 80 Some benefits that can be expected from extending TOC concepts to the supply chain include:
- reductions in supply chain inventories;
  - increased responsiveness and flexibility as inventories and wasteful obstacles and barriers to effective production are removed;
  - improved on-time delivery performance to the final customer;

- enhanced value creation for customers;
  - improved profitability/throughput for the supply chain;
  - reductions in total assets invested in the system as only essential increments to available capacity are added;
  - simplification of relationships as objectives are clarified;
  - reductions in cost across the supply chain; and
  - improved competitive position.
- 81 To optimize the benefits of integrated supply chain management, the separate organizations have to come to operate as one synchronous whole that follows the same “drummer.” The analogy to the DBR element of TOC is not accidental. Just as the internal flow cannot move any faster than the bottleneck allows, the entire supply chain cannot deliver more throughput than the slowest operation in the system, no matter where that constraint is located. If the trading partners are aware of the constraint, innovative solutions to ease its impact on system profits and performance can be sought and implemented.

### Market Segmentation

- 82 A market is effectively segmented when an organization can sell exactly the same product at two different prices to two different markets, without having either market affected by the other. The perfect example is airline seats. The same seat can sell for a whole variety of prices depending on how far in advance it is booked, whether or not an individual flies over a Saturday night, what privileges regarding cancellation are required, etc. Key to market segmentation efforts are:
- product mix decisions; and
  - product pricing decisions.

### *Product Mix Decisions*

- 83 Whenever a limitation exists restricting the amount of product that can be produced, a decision must be made to choose one product (or product line) over another so that profits can be maximized.

The criteria used to drive the segmentation decision include:

- strategic focus and long-term objectives for the products;
- existing agreements with trading partners (suppliers or customers) that would limit the extent of changes that can be made to the existing mix;
- the relative contribution margin of the available products and services;
- demand for the various product/service bundles;
- impact of the various products on the constrained resource;
- interdependence, or complementary purchase patterns for two or more of the available products;
- purchased resource constraints, such as long lead times, that affect the flexibility of the process; and
- the cost and availability of outsourcing to offload critical constraints if the problems are short-run in nature.

84 In the past, the key financial model used to address the allocation of capacity of a constrained resource has been contribution margin analysis. Separating the fixed from the variable costs of production, contribution margin analysis under constrained resource conditions would apply the following logic:

- identify the contribution margin per unit for each product;
- measure the amount of the constrained resource consumed by each product;
- divide the product contribution by the amount of constrained resource used to derive contribution per unit (e.g., minute) of constrained resource used; and
- prioritize products based on relative contribution per constrained resource, optimizing the amount of the highest contributing product/service (up to its demand level), on down to the lowest performing item.

85 Contribution margin, or the price less the variable cost of a specific product/service bundle, is a traditional management accounting concept that has long been a staple of the cost management tool kit.

Breakeven analysis emphasizes the volume of product needed to cover the costs of production. It is calculated by taking the total fixed costs of doing business and dividing them by contribution margin per unit. Breakeven, or cost-volume-profit analysis, has been used as a means to ensure that existing or new products provide enough revenue to ensure some level of profitability.

- 86 Within the TOC world, the concept of capacity-constrained market segmentation shifts away from emphasizing the gap between price and costs to a much simpler focus on maximizing throughput. Throughput, revenues earned by the productive process less any purchased costs (note: production for inventory does not yield throughput), becomes the key to choosing one product over another if such choices need to be made.
- 87 The logic of the calculations made, namely, to maximize the profitability earned from the constrained resource, remains the same as in traditional contribution analysis. Substituting throughput value for the contribution margin, though, can create markedly different rankings in the products chosen for primary versus nonprimary production.
- 88 The key difference in the two approaches lies in the assumption regarding what part of the system should be emphasized. Specifically, TOC is based on the belief that managers should try to increase the return from the money invested, an approach that emphasizes revenue maximization for the organization. Arguing that labor and variable operating expenses are more fixed than variable under actual operating conditions, TOC treats these costs as investments already made to get the system ready to produce. As long as no increases or increments in these costs are triggered by the chosen schedule, they are felt to be irrelevant to the scheduling decision.
- 89 If queried on the topic, most financial practitioners would agree that the cost structure of the organization is increasingly fixed in nature (at least in the short term). Given this fact, it still holds that the relative amount of total cost caused by the schedule has to incorporate any increments in resources used. Understanding the

cost structure of the organization, in which various stepped fixed costs are likely to be increased due to shifts in production, is a critical role for management accounting in a TOC setting. The simple logic of TOC builds on the belief that there are only throughput and a cluster of other costs called operating expense. A failure to recognize the complexity of the latter, in terms of relative capacities and potential incremental costs, could lead to a loss of profitability. It is management accounting's task to ensure that this unfortunate result does not happen.

- 90 In the TOC environment, the priorities in decision making begin with the optimization of throughput, then move on to inventory and operating expense as the second and third concerns of management. The goal is to balance the marketing, product development, and expenditure control efforts of the organization. The belief is that this approach will give superior results on all key entity measures, including stability, economic value-added, and return-on-investment.
- 91 As long as customer preferences and requirements are placed as the first criterion in the entire decision process, whether TOC-based or not, the logic presented here can be beneficial to the organization. The key, as is the case in most situations, is to keep a balanced perspective. Clearly, an excessive focus on cost reduction at the cost of customer satisfaction or actual organization profitability is not only illogical, it is bad business. Yet it is equally dangerous to emphasize only one dimension of performance, whatever it may be, to the exclusion of other indicators.

### *Product Pricing Decisions*

- 92 Product pricing is the key issue in the strategic positioning of any organization. While price is usually set by the market, the acceptance of any order must include the seller's approval. Price acceptance is usually a function of the predicted profit margin obtained from the algorithm sales price minus cost of goods sold. [Exhibit 6](#) illustrates three possible market segments.

Exhibit 6. Product Pricing in Segmented Markets

Product AFG	Current Market	New Incremental Market 1	New Incremental Market 2	
	Traditional Analysis	Throughput Analysis	Throughput Analysis	New Market Requirements
Selling price	\$300	\$200	\$100	
Material	80	80	80	No constraints
Labor	60			No additional labor
Variable overhead	120			No additional overhead
Total variable cost	\$260	\$80	\$80	
Contribution margin	\$40	\$120	\$20	

- 93 The first column in the exhibit represents the current market being supported by the XYZ company, in which product AFG is being sold for \$300 and has a standard cost of \$260. The sales group has informed management that two additional markets are available if prices can be dropped. In the first market, prices must be dropped to \$200, and in the second, to \$100.
- 94 Traditional cost accounting would place the losses for the \$200 segment at \$60 per unit sold, and the \$100 segment at \$160. Most organizations would understand immediately that a certain amount of overhead can be spread over the new order and so the orders for the \$200 market would be grudgingly accepted. Since the price in the \$100 market does not cover raw material and labor costs, it would be rejected. However, as with the make/buy decision, the impact based on a cost matrix is totally unknown. If the parts for the new market segments were to be made at nonconstraint

resources, no additional labor would be required to handle new orders. Labor is a nonvariable expense in that, unless overtime was expended or personnel hired, payroll would remain at 40 hours per employee per week. Figured this way, the profit for the \$200 market would be \$120 per unit, and for the \$100 market, \$20 per unit.

- 95 In segmented markets for an organization using nonconstraint resources, the price should be the highest price that can be obtained above the price for raw materials. Any new orders may threaten production capacity. If a part is made using resources for which additional production is required, inventories will increase.
- 96 If the part were to be made at the constraint, the amount of throughput per unit of the constraint would need to be compared to what is currently being produced and, if found to be less, the order should not be taken unless other circumstances dictate. If the \$300 and \$200 segments were creating an internal constraint, it is obvious that taking an order from the \$100 segment would mean a loss of an order from either of the two other segments. To properly segment the market:
- the sale of a product in one market segment should not have a negative impact on the sale of a product in another market segment;
  - each market segment must use the same resources; and
  - the segments should be flexible, so when demand in one market is down, the organization will still have adequate business from the other segments.
- 97 Under TOC, to accept an order, the sales representatives must know:
- the amount each unit of the constraint is currently being sold for;
  - how much of the constraint will be absorbed by the product in question;
  - what the customer is willing to pay; and
  - whether the order will have a negative impact on nonconstraints.

## Performance Measurement

- 98 The proof of effectiveness for any change effort is the degree to which it improves performance. TOC is no exception to this rule. How do organizations know whether the improved management of its constraints has had a positive effect on their overall system? A related question, namely, “How do organizations measure the effects of local decisions on their ability to reach entity goals?” places the emphasis on appropriately optimizing system performance, not individual results.
- 99 The assessment needed to determine whether an improvement has occurred begins with the validation of the touted improvements against some standard. While measurements such as return on investment (ROI) are often used, it sheds little light on whether an improvement has occurred based on the application of the TOC model. ROI also does not provide insight into where to focus to produce further improvements. Among the class of measurements that, due to their ex post nature, make management happy or sad, but not smarter; ROI and most traditional measures need adjustment or replacement as new methods, models and mindsets are adopted by the organization.
- 100 For an organization’s decision process and actions to achieve ongoing process and systemic performance improvements to work, there must be a direct linkage established between the financial measurements used, such as net profit and ROI, and those used operationally. TOC is particularly effective in establishing this connection.

### *Operational Measures*

- 101 TOC measurements are based on a simple relationship that highlights the effect that any local action (i.e., constraint management) has on progress toward the organization’s goal. All of its measurements, both financial and operational, build from the same three basic concepts—throughput, inventory, and operating expenses.
- *Throughput (T)*—the rate at which the entire system generates money through sales (product and/or service). T is represented

by the formula

$$\text{sales} - \text{purchased material costs}$$

To calculate T, subtract all money that has not been generated by the organization. However, other amounts must also be deducted from sales revenue when calculating throughput, including:

- subcontracting costs;
- commissions paid to salespeople;
- customs duties; and
- transportation, if the company does not own the transportation channel.

To illustrate, suppose that an organization sells a product for \$50. If the product contains parts or components that are purchased from vendors for \$15, sales commissions are paid in the amount of 10 percent on each sale (\$5), and transportation costs are \$1 per shipment, the throughput is \$29.

- *Inventory (I)*—all the money the system invests in things it intends to sell. Inventory includes any physical inventories such as work in process, finished goods and raw material. Some practitioners consider I as all the investment the system has made and includes, in addition to all the physical inventories, tools, buildings, capital equipment and furnishings. In TOC, the value of I does not include the value added by the system itself—specifically, inventory value does not include the value of direct manufacturing labor and manufacturing overhead. Instead, inventory includes only amounts paid for components that are purchased from outside vendors and used in the manufacture of inventory.
- *Operating expenses (OE)*—all the money the system spends turning inventory into throughput. OE include expenditures such as direct and indirect labor, supplies, outside contractors and interest payments. These costs are considered operating expenses because the employees are all responsible for turning inventory into throughput. Depreciation is also classified as an operating

expense because it represents a cost of turning inventory into throughput.

102 One might reasonably ask, Why bother with throughput, inventory, and operating expense? The traditional financial measures—net profit, ROI, and cash flow—tell us all we need to know. From a financial reporting standpoint, this is probably true. But daily operating decisions are made at the operational level, not usually in the finance office. It is not easy for line supervisors or middle managers to decide how their actions might affect net profit, ROI, or cash flow. However, throughput, inventory, and operating expense are more easily understood in relation to operational decisions, for example:

- Will the decision result in a better use of the worst constrained resource?
- Will it make full use of the worst constrained resource?
- Will it increase total sales?
- Will it speed up delivery to customers?
- Will it provide a characteristic of product or service that competitors don't have?
- Will it win repeat business for us?
- Will it reduce scrap or rework?
- Will it reduce warranty or replacement costs?

103 If the answer to the preceding questions is yes, then the decision will improve throughput (T).

- Will we need less raw material or purchased parts?
- Will we be able to keep less material on hand?
- Will it reduce work-in-process?
- Will we need less capital facilities or equipment to do the same work?

104 If the answer to the preceding four questions is yes, then the decision will decrease inventory (I).

- Will overhead go down?
- Will payments to vendors decrease?

- 105 If the answer to the preceding two questions is yes, then the decision will decrease operating expense (OE).
- 106 These are all decisions that middle management and line supervisors can make, assuring a favorable effect on net profit, ROI, and cash flow without even understanding those financial terms.
- 107 How T, I, and OE are used in operational decisions is as important as their definitions. Simple algebra illustrates that net profit increases when T goes up or OE goes down. Furthermore, T can go up by increasing sales revenue or by reducing variable costs of production. Anything done to increase net profit also improves ROI, as long as I remains the same. If I can be decreased, ROI goes up even without an increase in net profit. In fact, the adoption of just-in-time/kanban systems is intended to do exactly that. Also, cash flow increases when either T goes up or the time to generate T is reduced. The assumption here, of course, is that the time saved is productively applied toward generating more T.
- 108 T, I, and OE provide the linkages between operational and financial measurement in the TOC model. These performance measures help a company understand how much money it is making and how best to leverage its capabilities to improve profitability. TOC is unique in that the questioning needed to improve profitability is applied at the operational level.
- 109 Unlike traditional performance measures, which focus on direct labor efficiency and unit costs, TOC measures concentrate on increasing throughput and decreasing both inventory and operating expenses. TOC emphasizes how efficiently an organization must manufacture its products for optimum success in the marketplace rather than how efficiently the organization must manufacture the product. In other words, TOC promotes creating products/services that customers need and value. The flow of production is set according to market demand. It is not determined according to the dictates of mass production and the use of cheap sources of materials, low direct labor, and machine efficiencies. Thus, a standard cost system whose goal is to increase efficiency may actually decrease throughput.

- 110 In evaluating performance, the ratios throughput over inventory and throughput versus operating expense can help management to consider both operational and financial performance measures simultaneously. As suggested by the following two performance measures, the marriage of the three core elements of TOC measurement (T, I, and OE) provide significant amounts of information about the productivity of the system and its ability to turn investments in resources into sales and profits. The higher the inventory turnover ratio, the greater the velocity of materials through the system, the greater its effectiveness. By emphasizing throughput over traditional financial measures, TOC ensures that the performance is not “created” by producing goods only to store them.

$$\text{Productivity} = \frac{\text{throughput}}{\text{operating expense}}$$

$$\text{Velocity of material flow} = \frac{\text{throughput}}{\text{inventory}}$$

- 111 Complementary operational measures would include on-time delivery, reductions in manufacturing lead time, improvements in physical inventory turns, and improvements in scrap, rework, returns, and adjustments made. Once established, these measurements can also be used to analyze the impact of each internal decision on other key financial metrics, such as external measurements of net profit and ROI.
- 112 These measures may relate directly to the traditional measures of net profit (NP), return on investment (ROI), and cash flow (CF). Net profit is essentially throughput minus operating expenses for a given period.

$$\text{NP} = \text{T} - \text{OE}$$

- 113 ROI is net profit divided by inventory (or investment).

$$\text{ROI} = \frac{\text{T} - \text{OE}}{\text{I}}$$

- 114 Cash flow is net profit (throughput minus operating expense) plus or minus the change to inventory for the same period.

$$CF = T - OE \pm I$$

- 115 In several organizations that have implemented TOC management systems, operations managers are evaluated on their performance against the overall company goals, which are to ship specific orders by specific dates using no more than a specific level of operating expenses and capacities and a specific level of inventories. Using measurements to create a new culture or mindset is a critical part of achieving these performance goals. Unaligned measurements serve as barriers to lasting improvements.
- 116 Additional local performance measures that can be used by TOC-based companies and are consistent with the financial objectives of the organization include:
- throughput-dollar-days;
  - local operating expense; and
  - inventory-dollar-days.
- 117 *Throughput-dollar-days*—a measure of due-date performance. This measurement deals with quantifying the magnitude of the deviation of the plant from its promised commitments to clients. It is computed by assigning to every late order a value equal to its throughput multiplied by the number of days the order is late. Ideally, throughput-dollar-days should be zero because there should be no late orders. The larger the throughput value of an order, the quicker this measure becomes large. It also increases as the degree of lateness goes up. This measurement of throughput-dollar-days is not restricted to measuring just a plant's deviation. It can also be very effectively used internally, to measure the delivery performance of every production department, work center and even the performance of functions such as engineering and accounting. Assigning responsibility for performance shortfalls on this measure is a key element of effective TOC management.

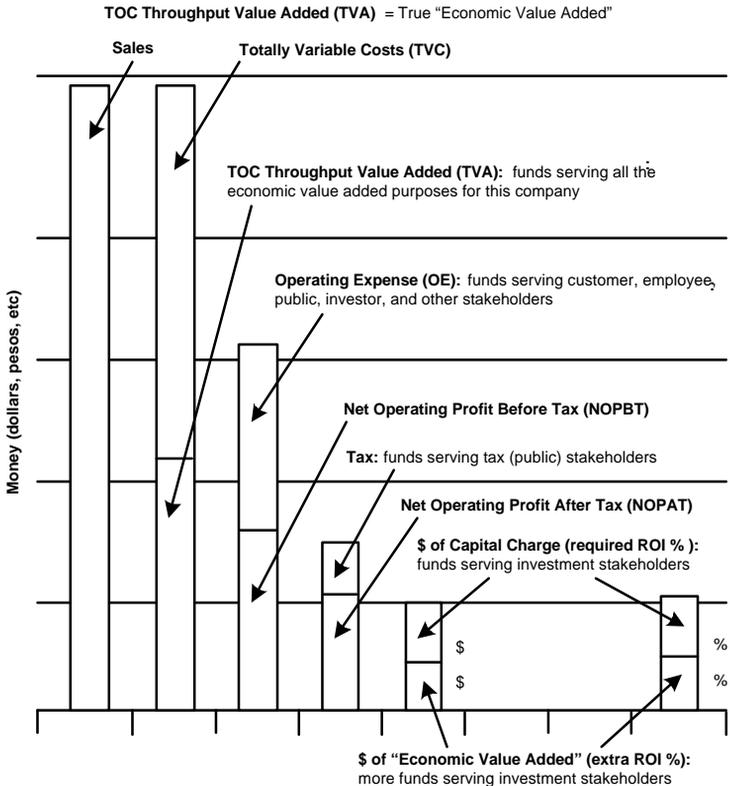
- 118 *Local operating expense*—a measure that simply compares variances between actual and planned spending in a responsibility center. Use of this measure should reflect the fact that managers should not be held responsible for expenses that occur outside their area of control. Uncontrollable expenses should not be assigned to an area. The establishment of planned expense for an area remains an open question in TOC, but most advocates suggest some form of budgeting or planning as the basis for this measure.
- 119 *Inventory-dollar-days*—a measure of excess inventories. The cost of finishing early can be represented by the amount of money invested in the inventory and number of days early the order is completed. Usually, more than one unit (department or worker) is responsible for an order being completed prior to the time the customer will take delivery, or a part being completed before it is needed. Inventory-dollar-days are designed to measure the extent to which a department or worker contributed to the early finish of an order or part. The seriousness of the excess inventories depends on how much has been invested in the inventories and how long that investment will last. Ideally, inventory-dollar-days should be zero.

### *Throughput Accounting (TA)*

- 120 Throughput accounting, TA, provides a well-defined set of performance measurements that physically link operational to financial results. Management can use these linkages to support the implementation of TOC. TA is a direct outcome of the use of throughput, inventory, and operating expense as management decision tools that replace most of an organization's traditional cost management reports and analysis.
- 121 TA operationalizes the key facets of TOC management. TA focuses management's attention on three basic objectives:
- increasing throughput;
  - reducing inventory; and
  - reducing operating expenses.

122 The emphasis in TA is on the underlying cash flow of the organization. In this respect, it is seen by proponents to be a source of reliable information for assessing the economic value added of the organization, as shown in [Exhibit 7](#).

Exhibit 7. Throughput Accounting (TA) and Economic Value Added



Source: McMullen, 1998: 99.

123 In TA the key leverage point is growth in throughput, the ability to "make the economic pie bigger." In the TOC world, not all economic or performance measures are equal. Protecting and increasing throughput value added (TVA: sales less true variable cost) is always

to be treated with higher priority than reducing inventory or reducing operating expense. Due to the higher importance of increasing TVA, decreasing operating expense should have a higher priority than decreasing inventory. Investment and operating expense levels should be controlled and, where appropriate, reduced whenever such reduction activities do not interfere with efforts to increase current or future TVA.

- 124 TA begins by reversing the accounting system's allocation of fixed costs to units of a product or service. Arguing that these costs are not changeable, or relevant, at the operational level, TA approaches eliminate them from the core measurement set used by managers. While the summary financial figures remain essentially the same, the absence of allocated fixed costs in the internal reports leads to very different management decisions concerning pricing and marketing for competitive advantage, just to name a few of the affected areas.
- 125 In essence, TA is variable costing done with increased levels of precision regarding the sorting of true variable costs from their stepped variable, stepped fixed, and mixed cost counterparts as illustrated in [Exhibit 8](#). The removal of direct labor and variable overhead results in a more precise application of variable costing. The use of this finer assignment of costs places an increased burden on management accounting to ensure that the underlying cost structure is well known, documented, and verified prior to use of the new performance measurements.
- 126 A second major difference between TA and traditional management accounting assumptions is the substitution of completed sales for traditional revenue calculations. In essence, TA uses a cash-based approach to revenue recognition, not booking in the "earnings" until the cash has been received on account. This is the most stringent of all the revenue recognition points, one where uncertainty of collection is close to zero, but the lag between completion of internal effort and the booking of revenue can be significant.

Exhibit 8. Variable versus TA

<b>Conventional variable costing</b>	<b>Variable costing with direct labor classified as fixed</b>	<b>TA</b>	<b>Simplified TA</b>
<b>Revenue</b>	<b>Revenue</b>	<b>Revenue</b>	<b>Revenue</b>
- direct materials	- direct materials	- totally variable costs	- direct materials
- direct labor			
- <u>variable overhead*</u>	- <u>variable overhead*</u>	= throughput	= throughput
= contribution margin	= contribution margin		
- <u>fixed expenses</u>	- <u>fixed expenses</u>	- <u>operating expenses</u>	- <u>operating expenses</u>
= <u>profit</u>	= <u>profit</u>	= <u>profit</u>	= <u>profit</u>
*variable overhead, both production and nonproduction			

Source: Noreen et al., 1995: 14.

- 127 For many organizations adopting TA, traditional revenue less the discounts and allowances applied is the starting point, as it is the most logical place at which to start. In fact, organizations that have failed to make this adjustment have experienced problems in implementing TA. The point is not when the revenue is earned but rather that inventory is never regarded as throughput within a TOC system.
- 128 A third major assumption of TA is that once a certain capacity level exists, that all the operating expenses associated with it are no longer actionable or changeable. It is this assumption that leaves TOC with only one point of leverage—throughput. Process improvements in the TOC world are solely focused on relieving constraints in order to increase throughput. The elimination of nonvalue-added work and related costs is not a primary objective. Within the organization, the entire decision process under TOC reduces down to increasing the return on money invested (operating expense and inventory) through revenue maximization.
- 129 A fourth difference in TA and traditional management accounting is that TA does not include the value added by the system in its

calculation of inventory values. Inventory only includes the purchased costs of materials and components that are to become throughput downstream. Traditional finished goods inventory, as well as excess work-in-process and excess raw materials inventories, are liabilities in the TOC world. They are costs that are not generating throughput, the key objective.

- 130 In the end, TA simplifies the traditional management accounting model, emphasizing key leverage points (throughput, operating expense, and inventory) and creating a decision hierarchy that aids in identifying optimal ways to improve profitability and the returns they represent. The simplifying assumptions made should be kept in mind when the system is used. When these assumptions seem invalid, it is important to make modifications so that the decisions made with the TOC-based information will yield their promised benefits to the organization.
- 131 For management accounting, TA is a useful tool for analysis, one that needs to be employed when applicable, developed in a reliable way, and accurately maintained and modified over time. The question is not whether TA or traditional accounting is the “right” way but rather, what form of information will prove to be most useful to management in their ongoing quest to improve the organization’s profitability and performance.
- 132 Bertch Cabinet Mfg., Inc. (Bertch) is a fully integrated manufacturer of wood cabinets and their accessories (e.g., mirrors) located in the Midwest. Bertch’s annual sales place it in the top 10 percent of U. S. domestic cabinet manufacturers. Bertch uses TA to assist management in their evaluation of the firm’s divisions and their products in terms of throughput margin. Other uses for TA information at Bertch are:
- in pricing decisions;
  - in establishing amounts to bid on new contract opportunities; and
  - in product emphasis decisions (based on throughput per unit of the constraint).

### *Constraints Accounting (CA)*

- 133 Constraints accounting is an accounting reporting technique, consistent with a process of ongoing improvement and implementation of TOC, which includes:
- explicit consideration of the role of constraints;
  - specification of throughput contribution effects; and
  - decoupling of throughput (T) from operational expense (OE).
- 134 An implementation doesn't become TOC until some methods for product flow control are utilized. This is difficult to do, let alone measure performance, until constraints are considered.
- 135 The throughput accounting measures of T, I, and OE offer a simple and clear way of comparing scenarios, hence are useful for many instances of decision support. However, constraints accounting goes much deeper. CA requires identification of the constraints as well as the means of monitoring them and understanding their behavior.
- 136 Hence, TA is essentially the understanding of the T, I, and OE notions and their application for decision support and in minor modifications to reports. And CA is a stage beyond, when there is acceptance of the need to know and measure physical constraints and after there is the capability to do that measuring and planning.

### VIII. TOC AND COST MANAGEMENT

- 137 TOC presents a significantly different perspective on how best to control operations. It does not work well with conventional accounting systems that emphasize cost absorption and standard cost variance analysis. The reasons for this are many, including the fact that building inventory to "earn hours" of labor and overhead is an alien concept in the TOC environment.
- 138 Within the more traditional cost management perspective, managers often focus primarily on decreasing the unit cost. Others may be less concerned with unit costs, placing their emphasis on decreasing the operating expenses and inventory (investment) of the

organization. In this setting, very few managers focus on increasing throughput or the output of the plant. According to TOC advocates, behind these worrisome trends lies the management accounting system and its excessive focus on unit costs and allocations. Specifically, they suggest that conventional cost management criteria are harmful in two ways:

- *Conventional approaches can distract attention from meeting the goal of the organization.* Shareholders of for-profit organizations expect to earn a reasonable return on the investment they make in the organization. If these expectations aren't met, shareholders are likely to take their money and invest elsewhere. Essential to an organization's long-term health, then, are satisfied shareholders. Satisfaction is increased by growing throughput and profit, outperforming competitors, and managing the organization for growth to keep customers satisfied. Costs should not be ignored in this process. They need to be put in their proper place, as the basis for evaluating priorities given constrained resource capabilities. Minimizing cost is not a growth strategy; maximizing throughput is.
- *Application of conventional accounting may actually decrease throughput and profits.* When cost is the primary measure of performance improvement, it often can lead managers to make significant budget and headcount cuts. As a result, organizations can end up milking the present to the detriment of the future. In the TOC model, identifying and managing the primary constraint is the primary objective. While downsizing and cost-cutting decisions may make sense in the context of a true financial crisis, they are not undertaken, without first analyzing what the constraint is and how it can be better leveraged to increase revenues. The goal is not to increase profits by reducing costs, but rather to find ways of improving the utilization of the fixed costs and resources of the organization to reduce waste and enhance profitability.

139 While TA is not a product costing method, it does borrow many of its core concepts from more traditional costing methods. There are

also significant differences in these two approaches to recording and reporting the financial performance of the organization. These differences can be better understood by looking at the core management accounting methods: absorption costing, variable costing, relevant cost analysis, and activity-based costing.

### Absorption Costing

- 140 Absorption costing develops a full product cost by combining the cost of raw materials, direct labor, and a “fair share” of manufacturing overhead. Absorption costing has been found to be inconsistent with a throughput environment because it penalizes managers who reduce inventories. Excess inventories are a signal that production should be cut back. This can lead to unabsorbed overhead in the traditional cost world, but under TOC reducing inventories results in increased throughput. The former can be seen as a negative result for a production manager, while the latter is the driving force behind TOC.
- 141 In TOC, inventory is to be eliminated; in absorption costing it is the basis for covering costs. If no immediate demand exists, absorption-driven logic would have a company make product ahead to “absorb” its overhead costs into inventory. Instead of absorption costing, most TOC companies use some variation of variable costing that begins with the assumption that direct materials are the only variable cost.

### Variable Costing

- 142 TA resembles variable costing because of its heavy emphasis on managing the incremental change in costs due to volume shifts (more throughput). At the conceptual level, throughput is very similar to the more traditional contribution margin estimate (contribution margin is simply sales minus all variable costs). The difference lies, as has been noted, in the fact that TOC uses a much stricter definition of variable cost than is used for contribution margin analysis. Specifically, some TOC proponents maintain that only the cost of raw materials should be deducted from sales to derive throughput. Others, though, take a more moderate approach, noting that any

cost that acts in a truly variable fashion should be deducted from revenue to determine throughput values.

- 143 While many similarities exist between TOC and variable costing, there is one significant difference: a product cost is not the goal of TOC. Seeing product cost as an arbitrary amount, the focus is instead on optimizing the performance of the system. Unitized information, such as traditional full product cost, is not useful in the quest to improve throughput within the system.

### Relevant Cost Analysis

- 144 Relevant cost analysis is a key element of TOC. As is noted in any reasonable management accounting text, though, relevant costs do not include all the cost elements found in a traditional product cost. As with traditional accounting models, TOC recognizes that costs that do not differ between alternatives are irrelevant to managerial decisions. The specific estimates TOC advocates that should be considered in decisions, such as when to add or drop a product, are operating cost reductions that will be experienced if production is eliminated compared to the reduction in throughput that the loss of the production will create.

### Activity-Based Costing

- 145 For many years there has been an ongoing debate about whether an organization seeking to break out of established paradigms that limited profits should use activity-based costing (ABC) or TOC. This is because decisions generated from the application of an ABC-based analysis are not always consistent with those suggested by TOC. The reasons for this result are numerous, including the fact that ABC considers all costs to be variable in the long run, the relevant time frame of analysis for many decisions. TOC, by contrast, is oriented more toward short-run optimization where most costs are fixed in nature.
- 146 A significant number of articles have been written about ways in which ABC and TOC complement each other. While the main proponents of these two management approaches may be at

conceptual odds, the reality of the fact is that each of these tools provides unique insights and information. The goal of management accounting is to understand which tool to use, when, and why.

- 147 The key issue is not only the different time orientations of ABC and TOC, but the fact that TOC addresses the concerns of machine-intensive departments while ABC has more information value for people-intensive areas. In people-intensive environments, the resources are flexible and redeployable, the employee paces the workflow and most of the resource costs are salary-based. In this setting, ABC is the key data source, because it penalizes those jobs that consume excess amounts of employee time and effort. It can also be used to drive improvement efforts to reduce the impact of these less routine orders and customers on the system.
- 148 Conversely, in machine-paced environments, the situation is quite different. Machines, not people, pace the flow and machines, not salaries, cause most of the costs. In this case, the costs are a proxy for the costs of creating and maintaining long-term capacity. Since the dominant costs in the system are inflexible and fixed, it makes little or no sense to focus attention on them in the short-run. For instance, a setup that is done using currently idle time has no incremental cost to the system, while one done when capacity is constrained (no idle time available) is very costly in terms of throughput. These facts drive TOC to place its emphasis on eliminating wasted time on the constraints rather than worrying about costs. Cost is not actionable in the short-run for the machine-intensive departments.
- 149 This type of logic drove the integration of TOC and ABC at a Kentucky distillery. While the simplicity of TOC had merits in terms of implementation speed within this organization, analysis suggested that TOC would oversimplify the underlying cost structure of the organization to such an extent that it might prove useless, or harmful, to long-term decision making. The optimal solution seemed to be to develop a hybrid system that utilized the best aspects of ABC and TOC. The resulting analysis, as suggested by [Exhibit 9](#), used TOC for manufacturing costs to derive the manufacturing “contribution,”

and ABC to analyze and charge the support costs (people-intensive) to the three primary product lines. This integration permits the distillery to answer traditional cost-volume-profit questions, facilitates the evaluation of profitable product lines, and better answers the question of 'bottom line profitability' by product and customer.

Exhibit 9. TOC and ABC Production, Marketing, and Administration

<i>(in thousands)</i>	<b>Bourbon</b>	<b>Gin</b>	<b>Vodka</b>	<b>Total</b>
Sales	<u>\$105,000</u>	<u>\$39,000</u>	<u>\$36,000</u>	<u>\$180,000</u>
Materials	31,500	11,000	11,750	54,250
Commissions	<u>5,250</u>	<u>1,950</u>	<u>1,800</u>	<u>9,000</u>
Net throughput	\$ 68,250	\$26,050	\$22,450	\$116,750
Advertising—direct	<u>3,000</u>	<u>1,500</u>	<u>1,400</u>	<u>5,900</u>
Contribution to indirect activities	\$65,250	\$24,550	\$21,050	\$110,850
Marketing—other	4,471	2,339	2,140	8,950
Administrative	6,163	3,247	3,040	12,450
Production overhead	<u>46,900</u>	<u>17,700</u>	<u>18,150</u>	<u>82,750</u>
Operating income	<u>\$ 7,716</u>	<u>\$ 1,264</u>	<u>\$( 2,280)</u>	<u>\$ 6,700</u>
Total gallons	<u>30,000</u>	<u>15,000</u>	<u>14,000</u>	
Net throughput/gallon	\$ 2.28	\$ 1.74	\$ 1.60	
Variable cost/gallon (material and commissions)	1.23	0.86	0.97	
ABC cost/gallon	3.24	2.52	2.73	

Source: Demmy and Talbott, 1998:22.

## IX. CONCLUSION

- 150 TOC brings a new dimension to management philosophy and provides an interesting challenge to the traditional ways of looking at an organization's profitability. Adopted within a wide variety of organizations and settings, it appears that organizations using TOC have determined that it can help them achieve a number of management objectives, including continuous improvement.
- 151 Using TOC, like any other form of information, should be guided by the purpose or requirements it is necessary to meet. In the end, the goal of every organization is the same; optimize profitability by meeting customer requirements better than the competition. It is this purpose the information system needs to serve.

## APPENDIX: Constraints Detail

### Behavioral Constraints

Behavior is an action or reaction to the environment and specific situations as they are encountered. Training, education, measurement systems, experiences, attitudes, and mental disposition all affect the behavior of the people involved. Whenever behavior is in conflict with reality and results in a negative impact on the global measurements of the organization, it is said to be a behavioral constraint. Many different stimuli cause behavioral constraints. Probably the most prevalent cause is linked to the measurement system. “Tell me how you will measure me, I will tell you how I will behave.” (Goldratt, 1990) Whether implicit or explicit, measurement systems dictate the way that people act. The best example of this is the concept of staying busy.

One of the hardest behaviors to change—and yet, one of the most devastating—is the concept that resources must “stay busy.” The assumption is that whatever an employee does to stay busy, the end result will be beneficial to the organization. This assumption is reinforced by the utilization measurement, whereby every resource must be highly utilized or else the organization will lose money. Management and employees alike hold on to this concept, although not necessarily for the same reasons. The extended result of this behavior is that inventories begin to climb, product mixes become unbalanced, schedules slip, and material shortages occur.

Another example of a behavioral constraint is the tendency to maximize savings during setup. Planning setup this way, without knowledge of the global impact on throughput, inventory, and operating expense, may result in a decline in profitability. When viewed from a global perspective, this approach may seem almost irrational, and the negative impact on profitability is often predictable. And yet it is very difficult to convince a foreman to act otherwise.

## Managerial Constraints

Poor management policies often make it impossible to use physical resources fully or to use nonconstraint resources properly to create throughput. As an example, a policy of setting commission schedules for sales representatives using activity-based accounting to determine which products to push onto the market may cause the poor exploitation of resources for maximizing profitability. Such a policy may, in fact, cause a serious decline in profitability. Or a policy of establishing quality cost as the mechanism for focusing improvement may result in money spent to improve an area that will not help to increase the overall profitability of the organization.

## Capacity Constraints

A capacity constraint exists any time the demand placed on a resource exceeds its available capacity. Capacity constraints can include machines or people and can restrict the creation of throughput. Primary constraints are those that restrict the output of the entire organization. Secondary constraints restrict the ability to subordinate properly to the primary constraint. In other words, if the demand placed on a resource increases to the point where the probability is low that it will be able to deliver what is needed to the primary constraint, the resource is said to be a secondary capacity constraint.

## Market Constraints

Perhaps the most important constraints to consider are those created by the market. The market controls the product, pricing, lead time, quantity, and quality of the goods and services demanded, and it establishes the necessary conditions for creating throughput. Whenever market demand is less than the capability of the organization's resources, a market constraint exists. While market constraints have many causes, most exist due to management policies.

## Logistical Constraints

Anytime problems occur that originate from the planning and control systems within an organization, there is said to be a logistical constraint. Material requirements planning systems that are capacity insensitive create problems in the proper synchronization of resources and can escalate the amount of inventory and production problems that already exist. For example, a cumbersome purchasing process in which for every purchase the lowest price must be selected from a minimum of three bids from three different vendors, may actually restrict the creation of throughput.

## GLOSSARY

- BOTTLENECK.** The constraint in a production flow process. The limiting capacity process step, or anytime the demand placed on a resource is equal to or greater than capacity.
- BUFFER.** In process inventory, time or budget allowance used to protect scheduled throughput, delivery dates, or cost estimates on a production process or project.
- BUFFER MANAGEMENT.** A technique used to manage the amount of protection necessary and the process of controlling the buffer regions within the plant.
- CONSTRAINT.** A process, process step, or anything that limits throughput and prevents the system from achieving its goal.
- CONSTRAINT SCHEDULE.** The schedule created for capacity-constrained resources in order to exploit a plant's productive capability.
- CRITICAL CHAIN.** The longest set of dependent activities, with explicit consideration of resource availability, to achieve a project goal. The critical chain is NOT the same as the one obtained by performing resource allocation on a critical path schedule. The critical chain defines an alternate path, which completes the project earlier by resolving resource contention up front.
- CRITICAL CHAIN FEEDING BUFFER (CCFB).** A time buffer at the end of a project activity chain, which feeds the critical chain.
- CRITICAL CHAIN RESOURCE BUFFER (CCRB).** A buffer placed on the critical chain to ensure that resources are available when needed to protect the critical chain schedule. This buffer is insurance of resource availability and does not add time to the critical chain. It takes the form of a contract with the resources that ensures their availability, whether or not they are to be used immediately, through the latest time they might be needed.
- DRUM-BUFFER-ROPE.** The drum-buffer-rope method for production scheduling. The drum is the capacity of the plant constraint and is used to set the overall throughput schedule. The buffers are in-process inventories strategically located to eliminate starving the constraint due to statistical fluctuations. The rope

is the information connection between the constraint and material release into the process.

**FIVE FOCUSING STEPS.** The five-step process to identify and elevate constraints.

**INVENTORY.** All the investment in the equipment necessary to convert raw material into throughput.

**OPERATING EXPENSE.** One of the key measurements used to manage a TOC organization. All the money it costs to convert raw material into throughput.

**STATISTICAL FLUCTUATIONS.** Common-cause variations in output quantity or quality.

**THROUGHPUT.** One of the key measurements used to manage a TOC organization. The rate at which the system generates money through sales.

**THROUGHPUT ACCOUNTING.** The use of the three basic measurements of throughput, inventory, and operating expense to manage the financial/accounting aspects of an organization and its decision making.

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