Theory of constraints: a theory for operations management

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Abstract

Purpose – The purpose of this paper is to suggest that the theory of constraints (TOC) can serve as a general theory in operations management. The paper first investigate linkages between TOC and the core concepts/components of operations management (OM) and show how OM concepts can be integrated with TOC using examples from the published TOC literature. A second important purpose is to show that TOC, as a theory, has properties essential for a good theory.

Design/methodology/approach – Using a commonly accepted categorization of operations decisions (process, quality, inventory and capacity), traditional views, and approaches to operations decisions to those inherent in the TOC are compared.

Findings – The paper concludes that the TOC provides approaches to operations decisions that avoid pitfalls of local optimization by reaching across functional boundaries in organizations. In addition, while the TOC appears to meet the criteria of a good theory, it has not been empirically tested for the most part.

Originality/value – The TOC can serve as a unifying theory or theme for operations management, providing new insights for researchers and an organizing principle for teachers.

Keywords Operations management, Management philosophy

Paper type Conceptual paper

1. Introduction

In the quest to improve manufacturing performance, a number of broad-based operations management philosophies, e.g. total quality management (TQM), just-in-time (JIT), or lean manufacturing (LM), theory of constraints (TOC), and more recently, six sigma (SS) and supply chain management (SCM) have been proposed in the literature and are being implemented in practice. It is widely held that the successful implementation of these philosophies requires systems thinking, functional integration, and flatter organizational structures. From the operations manager's perspective, these practices require managers to work on cross-functional implementation teams and participate in cross-functional decision-making processes. To do so, managers need a common language, the language of theory (Handfield and Melnyk, 1998). Areas such as marketing, finance, strategy, and organizational behavior are well grounded in theory-development methods but the need for theory-building, testing, and modification in operations management (OM) has been widely recognized (Meredith *et al.*, 1989; Flynn *et al.*, 1990; Swamidass, 1991; McCutcheon and Meredith, 1993).

Westbrook (1995) suggested that OM academics must embrace creative tension between theory and practice and must develop new theories from the observation of actual practices. Theory development remains the most fertile research area in the field of operations management (Westbrook, 1995; Pannirselvam *et al.*, 1999). A number of attempts have been made to develop and propose theories and theory-like principles of

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operations management. These attempts include: trade-off theory (Skinner, 1969), the process-product matrix (Hayes and Wheelwright, 1979), the customer-contact model (Chase and Tansik, 1983), the TOC (Goldratt and Cox, 1984; Boyd and Gupta, 2004), the cumulative theory (Ferdows and DeMeyer, 1990), the theory of production competence (Cleveland *et al.*, 1989; Vickery, 1991), priority management theory (Westbrook, 1994), the theory of TQM (Flynn *et al.*, 1994; Handfield and Melnyk, 1998), the theory of swift and even flow, and the theory of performance frontiers (Schmenner and Swink, 1998). This list is not exhaustive but rather an attempt to highlight major initiatives undertaken in the academic OM literature. Schmenner and Swink (1998) further suggested that these theories in operations management should be carefully examined, refined and, if warranted, abandoned.

In this paper, we examine the TOC as a unifying theory in operations management. A significant number of journal articles have been written:

- to trace the history of optimized production technology, the predecessor to TOC (Goldratt, 1988; Fry *et al.*, 1992) as well as that of TOC (Gardiner and Blackstone, 1994, Watson *et al.*, 2007);
- to review the basic concepts of TOC (Ronen and Starr, 1990; Fawcett and Pearson, 1991);
- to categorize TOC concepts and terms (Spencer and Cox, 1995);
- to review TOC literature (Rahman, 1998; Balderstone and Mabin, 1998) and successful applications (Mabin and Balderstone, 2003, Kim *et al.*, 2008);
- to demonstrate applications of TOC in various areas such as SCM, enterprise resource planning, sales and marketing, human resource management (Blackstone, 2001), and strategic planning (Gupta *et al.*, 2004)
- to highlight its current applications (Gupta, 2003); and
- to place it among extant operations research/management science methodologies (Davies *et al.*, 2005).

From a review of these articles, we conclude that the basic concepts of TOC have been fully described and have not changed significantly over the past decade or so. TOC terms are summarized in two dictionaries – Blackstone and Cox (2008) and Sullivan *et al.* (2007).

Boyd and Gupta (2004) established TOC as a theory by clearly identifying the underlying construct "throughput orientation" along with its three dimensions: Mindset, Measures and Methodology. This paper goes beyond that by showing that TOC can serve as a unifying theory in operations management. A major contribution of this paper is to demonstrate how existing principles and concepts of OM (sometimes referred to as a tool kit) discussed in the published literature can be viewed as an integrated whole (Section 2). In addition, for researchers to accept TOC as a theory in OM, they must see that it meets the established criteria for a good theory. We believe that the second major contribution of this paper is showing that TOC meets these criteria (Section 3). Thus, the current paper further extends the existing body of TOC literature and also fills a gap identified in the OM theory development literature.

2. A theory of constraints-based framework for operations management

The Section 1 mentions a number of theories in OM, none of which is comprehensive or serves to integrate the wide variety of concepts or methods considered part of OM. Several schemes or approaches (e.g. structural and infrastructural; long-, intermediate-, and short-term; tactical and strategic; and more recently, designing and planning the supply chain) have been proposed to classify OM concepts; however none of them provides an underlying theory that shows how the concepts and methods of OM are interrelated. A brief review of OM textbooks authored by leading OM scholars (Chase *et al.*, 2006; Slack *et al.*, 2006; Krajewski *et al.*, 2007; Stevenson, 2007; Heizer and Render, 2008; Schroeder, 2008) reveals that the organization of OM concepts appears to differ among books based on each author's preference rather than differences in underlying theory[1]. The books almost always cover certain topics, including operations strategy, measures of operational performance or operations priorities, and major OM decisions. Schroeder (2008) organizes his textbook around the four categories of operations decisions: processes, quality, capacity and inventory. We will combine the three dimensions of TOC and Schroeder's four categories in order to structure the discussion of the relationship between TOC and traditional OM concepts. In this section, we demonstrate that the three dimensions of TOC – mindset, measures and methodology – can be viewed as a framework for OM (Table I).

2.1 Operations strategy and organizational mindset

2.1.1 The transformation system and cross-functional perspective. Traditional OM textbooks view OM as responsible for managing the process of transforming inputs into outputs. There is an increasing emphasis on the management of processes and the cross-functional nature of processes. TOC emphasizes the cross-functional and interdependent nature of organizational processes by viewing an organization as a chain (or a network of chains) of interdependent functions, processes, departments or resources where a variety of inputs are transformed into a variety of products and services which when sold become throughput. Although it is possible to view the production/operations function as a functional area with a distinct set of inputs and outputs, in the view of TOC the role of operations must be evaluated in the context of the whole organization. Cox *et al.* (2003) goes beyond other OM textbooks in developing a "business systems model" incorporating organization structure, business processes and management direction as a framework for discussing the use and impact of TOC concepts on the whole organization.

The rate of output of the whole system determines the rate at which the purpose (the goal) of the organization is accomplished. TOC further defines a constraint as anything that limits an organization's higher performance in terms of its goal. When viewed from a functional perspective (e.g. the operations function), a list of problems, often loosely defined as constraints, can be quite long, representing problems in each function or department. However, the chain analogy suggests that not all problems can be the weakest link(s) in the chain; some problem has to be the most significant with respect to the organization's ability to move in the direction of its goal. This weakest link could be a resource the company does not have enough of (a physical constraint) or lack of market demand for its products, poor relationships with suppliers, or other policies, procedures or ways of thinking. All of these latter types of constraints are referred to as non-physical constraints. Thus, it is possible, for example, that the

Table I.
A TOC-based framework to integrate OM concepts

Operations management	Constraints management	Main references
Operations strategy	*Mindset*	Goldratt (1990a,b)
A transformation system	A chain and the weakest link(s)	Goldratt (1992)
Business/functional strategies	Throughput-world thinking	Dettmer (1997)
	Strategic location of the constraint	Kendall (1998), Ronen and Pass (2007)
Cross-functional nature	The goal and necessary conditions	Boyd and Gupta (2004), Cox *et al.* (2003)
Competitive priorities	*Measures*	Srikanth and Robertson (1995)
Quality, flexibility, dependability, efficiency	Throughput, inventory, and operating expenses	Goldratt (1990b), Corbett (1999)
Productivity, inventory turns	Throughput dollar days and inventory dollar days	Goldratt (1990a), Cox and Spencer (1998)
Major topical decisions	*Methodology*	Srikanth and Umble (1999)
Process management	Dependent events, V-A-T analysis	Goldratt (1990b)
Quality management	Process of ongoing improvement	Goldratt (1984)
Statistical quality control	Statistical fluctuations	
Capacity management	Constraint/non-constraint resources	Goldratt (1984)
Inventory management	Buffer management and drum-buffer-rope	Goldratt (1990b), Cox and Spencer (1998)
Other topical coverage	*Methodology*	
Linear programming	Throughput per constraint minute	Goldratt (1990a), Mabin and Davies (2003)
Project management	Critical chain	Goldratt (1997)
Supply chain management	Continuous replenishment system	Goldratt (1992)
Enterprise resource planning	*Necessary But Not Sufficient*	Goldratt *et al.* (2000)

operations function does not have enough of a specific resource or a specific resource is not utilized properly due to some policy constraints, thereby limiting the performance of the entire organization of interdependent resources, departments and processes. Thus, TOC promotes very strongly an integrated, cross-functional and systems view.

2.1.2 Operations strategy. The OM literature emphasizes the importance of the operations strategy being consistent with both the business unit strategy and with the other functional area strategies such as marketing and human resources. Constraints management goes beyond this emphasis on consistency linking to the focus on the organization's goal of "making money now as well as in the future" without violating the necessary conditions of providing a satisfying work environment for employees and ensuring customer satisfaction (Goldratt, 1994; Cox *et al.*, 2003; Boyd and Gupta, 2004). The mission statements of many successful organizations reflect this goal and necessary conditions. This aspect of TOC provides a common mission to be accomplished by the business unit and all functional areas, including the operations function.

Although the necessary conditions of employee and customer satisfaction have long been established as core concepts of TQM, TOC emphasizes that these are threshold conditions whereas in the for-profit organization, the goal of making money is something to be continually striven for. In the TOC view, a firm considering its strategy first measures the level of these two necessary conditions and if minimum levels have not been met, they must be addressed first before the firm does anything else. If the firm is losing customers or has high employee turnover, the reasons must be determined and corrected before attention is turned to making more money.

Another strategic concept of TOC is throughput-world thinking (TWT), i.e. the organization should devote its energy primarily to increasing throughput, for example by exploring new markets, introducing or modifying new products or simply selling more of existing products or services, rather than devoting attention to reducing costs or saving money, referred to as cost-world thinking (CWT).

The final strategic concept of TOC is that the location of the constraint within the organization must be strategically determined, i.e. management must make a conscious decision concerning what resource or capability should be the organization's most limiting factor (Goldratt, 1990a; Cox *et al.*, 2003; Ronen and Pass, 2007). In many cases, the constraint will be the most expensive or scarce resource and should therefore determine the strategic direction of the organization (Section 2.3.3 provides additional discussion of this issue).

In conclusion of this section, we have attempted to show how the mindset construct of TOC comprehends existing OM concepts as summarized in Table I.

2.2 Measurements: OM perspective

In the traditional operations management literature, discussion of measures includes the four operations objectives of dependability, efficiency, flexibility and quality (Schroeder, 2008). The measures of these objectives are discussed in the context of the need for consistency between the operations strategy and other functional area strategies mentioned above. In addition, depending upon the business strategy, specific objectives become more important than the others and excelling in those areas serves as the organization's competitive advantage. Cox *et al.* (2003) provide a more comprehensive treatment of measures, including the relationships of the three major performance measurement systems in an organization – the financial, operations and customer (marketing) performance measurement systems. They conclude that integration of these three systems is necessary because focusing on measures in each functional area separately results in suboptimal results for the organization as a whole.

Because it is human nature to respond to measures ("what gets measured is what gets done") TOC gives measures a more central role than does the OM literature and proposes a set of measures – throughput, inventory and operating expenses – that tie the impact of local decisions and actions to the company's goal of making money. Although the terms used for the measures are very common in the OM literature, they are used in a specific way in TOC.

For example, throughput, in the OM literature, refers to the output rate of a subsystem or of a system as a whole. In TOC, however, throughput is defined as "the rate at which the system generates money through sales." There are several important distinctions here. First, in TOC, anything produced but not sold is not considered throughput. The implication is that the operations function must produce, the marketing function must sell, and the accounting function must report the income from the sale of a product before it is considered throughput. This aspect of throughput as defined by TOC encourages cross-functional coordination. Second, in TOC throughput is defined in financial terms rather than units so it can be used to measure the organization's progress toward its goal of making money.

Similarly, inventory, in operations management, refers to raw material, work-in-process, and finished goods inventories. Generally accepted accounting principles require reporting inventory on the balance sheet as an asset valued at cost of raw material plus value added – the labor and overhead used to produce the inventory. This valuation method encourages organizations to build inventory even though it cannot be sold immediately because portions of operating expense are shifted to the balance sheet as value-added, resulting in higher reported profits in the short-term. However, inventory in TOC is reported as the cost of raw material only and does not include value-added. In addition, the term inventory is defined broadly to include all the money "stuck" inside the organization, so all buildings, equipment, fixtures, tools and other investments in assets are also classified as inventory. Thus, from an operations management perspective, decisions to reduce inventory as defined in TOC are consistent with the actions suggested by JIT and LM.

Finally, operating expense, in the operations literature, refers to the non-product costs of producing products and services. In TOC, operating expense refers to the money going out of an organization in terms of salaries and wages, rent, utilities and any other cost that does not vary directly with units of product or service produced.

In the TOC view, the goal of an organization (i.e. to make money) is accomplished by increasing throughput while at the same time reducing inventory and reducing operating expenses. While this is the ideal situation, the primary emphasis should be on increasing the rate of throughput with secondary emphasis on reducing inventory, while efforts to reduce operating expenses should be a clear third in importance. In the TOC view, operating expenses are the cost of opening the doors and turning on the lights, and while such costs can be decreased in the short-term, doing so can have two negative effects:

(1) it will take management's attention away from increasing throughput; and

(2) it will almost inevitably harm the necessary conditions of employee and customer satisfaction.

Management gets much more “bang for its buck” by focusing on increasing throughput, which has no theoretical limit, rather than focusing on reducing operating expenses, where a 10 or 20 percent decrease is considered significant but is difficult to maintain.

In conclusion of this section, we have attempted to show how the measures construct of TOC comprehends existing OM concepts as summarized in Table I.

2.3 TOC methods to address major OM decisions

2.3.1 Process management. Cox *et al.* (2003), as well as most traditional OM textbooks, address the operations issues involved in designing the transformation process (facility design, selection of technology, personnel selection, etc.). In some cases operations managers make a conscious process design decision to support the selected business and product strategy. In many cases, however, processes change incrementally as a business grows and the process in use at any point in time may not be the ideal process an operations manager would have chosen to meet the current requirements of the business. In the former case, process design is a major issue while in the latter case process management is more important up to the point where the process can be redesigned.

The TOC literature focuses on management of an existing process. The guidance provided by TOC for managing processes is at three levels. First, at the highest level, TOC views all operations systems as consisting of a set of interdependent processes where the output of one process is an input to another process or processes. The number and type of interdependencies that exist in a given plant will be a function of product varieties, production processes and a number of other factors. In any complex system, there are only a few points, the constraints, which have a significant, immediate impact on the whole system. Management of the organization’s constraint or constraints at this level is addressed by following the five focusing steps (Goldratt, 1984):

(1) Identify the system’s constraint.

(2) Decide how to exploit the system’s constraint.

(3) Subordinate the rest of the system to the decisions made above.

(4) Elevate the constraint.

(5) Go back to Step 1.

Second, at the operations level, TOC introduces the concept of the logical product structure (LPS) and V-A-T analysis (discussed below). Third, at a detailed level, TOC introduces the drum-buffer-rope (DBR) production scheduling method and buffer management, which will be discussed in the inventory section below.

The TOC literature introduces the concept of the “LPS” for each product or product family (Goldratt, 1988). The LPS can be seen as a combination of a product routing and bill of material and shows how raw material flows through the various operations in a plant to form a finished product. The LPS identifies part numbers, operations performed, and the resources used at various steps in the transformation process for a product or product-family. The LPS highlights three points of special interest to operations managers:

(1) divergence points where a material may be transformed into two or more distinctly different materials/parts/products;
(2) convergent assembly points where two or more materials/components are assembled to form a single part/product; and
(3) divergent assembly points where a variety of common parts may be combined to form a large number of possible products/parts (Goldratt, 1988; Umble and Srikanth, 1997).

Generally, one of these three categories of points will dominate the interactions among products and resources in a plant, leading to three basic plant classifications: V-plants, A-plants and T-plants. The V-A-T classification of plants provides insights into the causes of common problems the three types of plants experience due to misallocation of resources, which is common at A-plants, and the misallocation of materials, which is common at V-plants and T-plants. These misallocations are generally due to managers responding to performance measures designed to achieve local optima (e.g. efficiency) but have a negative effect on profitability.

2.3.2 Quality management and continuous improvement. Founders of the quality management movement such as Deming, Juran, Ishikawa, and Crosby noted that TQM requires changes in the values, beliefs, and assumptions about how a business should be managed. The core TQM practices include statistical process control, improved product development processes, and process management. These practices also include infrastructural issues such as customer and supplier relationships, work attitudes, employee empowerment, and top management support (Flynn *et al.*, 1995).

Although many US firms have benefited from the TQM philosophy and have incorporated it into their strategic planning process, the TQM philosophy has also been assailed by some scholars and managers as faddish and destructive (Hackman and Wageman, 1995; Zbaracki, 1998). Many TQM firms, even the winners of national and international industry quality prize competitions, have failed to develop and sustain a competitive edge, and others, frustrated by the lack of visible improvements and positive financial results, have questioned the value of the TQM philosophy (Fuchsberg, 1992, 1993; Hill, 1993; Wilkinson *et al.*, 1995; Simatupang and White, 1998).

Many researchers have considered the similarities and differences between TQM and TOC (Lockamy and Cox, 1994; Ronen and Paas, 1994; Dettmer, 1997; Stein, 1994). In addition, some researchers have attempted to demonstrate that TQM and TOC are not mutually exclusive, but that the TOC approach can be viewed as building on the foundations established by TQM (Lepore and Cohen, 1999; Boyd and Gupta, 2004). Lepore and Cohen (1999) suggest a ten-step process, *The Decalogue*, which attempts to integrate the TOC and the system of profound knowledge proposed by Deming. They show how the proposed process can employ TOC-based tools to implement Deming's philosophy.

One of the major differences between the TQM and TOC philosophies is that TQM does not differentiate between the goal and necessary conditions (Boyd and Gupta, 2004). TQM proponents appear to argue that employee satisfaction leads to customer satisfaction and retention which leads to company financial success and which in turn provides employees with security and satisfaction (Rucci *et al.*, 1998; Heskett *et al.*, 1994). Viewed as a loop, it may not matter what we call the goal as long as the other two are considered as necessary conditions. However, from the TOC perspective, the major difference between the goal and necessary conditions is that the goal is something a company wants to increase continually whereas the necessary conditions must simply be met, i.e. a threshold level must be achieved but increasing the level beyond the threshold does not result in an increase in profit. More importantly, TOC also poses a question as to what is limiting (constraining) the company from continually increasing its performance with respect to its goal of making money. There is some evidence that the current movement toward SS, a project oriented approach to quality management, is driven by the fact that the process improvement initiatives must result in cost savings or anincrease in sales and some are using TOC to help decide on the required focus (Ehie and Sheu, 2005).

In addition to establishing the necessary conditions of employee and customer satisfaction, the TOC philosophy proposes a five-step method of focusing firm-wide effort for continuous increase in profitability. These five focusing steps can be compared to the Deming cycle of plan, do, check and act. The major difference between the two approaches is that while TOC explicitly recognizes that there is a single constraint within the system limiting throughput, TQM seeks to improve quality across the system without any particular priority. Consequently, in a quality management environment, it is conceivable that resources might be expended to improve non-bottleneck processes, which will not affect the system's throughput but will increase expenses. One of the significant lessons of TOC is not only that efforts that result in increased efficiency of a non-bottleneck process are wasted but also that operating non-bottleneck resources to maximum efficiency will create excess inventory. The tools of quality management (e.g. process flow charts, cause and effect diagrams, and process control charts) can, however, be employed effectively within the framework of the five focusing steps of TOC to either identify or exploit (make the best use of) the system's constraint(s). In other words, the five focusing steps and goal/necessary condition framework of TOC can be used to focus quality improvement efforts where they will have the greatest impact. Of even greater significance is that if the mindset of top management is CWT, the inefficiencies identified through quality management programs might be translated into bottom line results through layoffs. Such actions are inconsistent with both the view of employee and customer satisfaction as necessary conditions and the profit chain discussed above. In addition, the thinking process tools of TOC provide techniques for identifying and solving root problems – which is a stated aim of TQM practices. Cox *et al.* (2003) provide some real-life examples of the applications of the TOC thinking process tools to quality problems.

2.3.3 Capacity management. The treatment of capacity in operations management is many times divided into long-term, medium-term and short-term capacity issues. TOC defers consideration of long-term capacity issues until after short-term capacity issues have been dealt with – via the five focusing steps framework:

(1) identifying the constraint, i.e. a process with insufficient capacity to meet demand;

(2) exploiting the constraint's existing capacity;

(3) subordinating the rest of the system to the constraint before acquiring additional capacity;

(4) elevating the constraint, i.e. adding additional capacity; and
(5) going back to Step 1 if a constraint is broken.

We should note that it is not always necessary to elevate the constraint. The choice of whether or not to elevate the constraint is a strategic decision (Ronen and Pass, 2007).

One of the most fundamental applications of the five focusing step approach is DBR scheduling. DBR is a finite-capacity scheduling method which ensures that the resulting schedule is capacity-feasible, thereby performing the same capacity planning functions as rough-cut capacity planning and capacity requirements planning in a traditional system (Cox *et al.*, 2003). In addition, managing the buffers in a DBR system performs capacity control functions similar to the function performed by input/output control in a traditional system.

TOC also does not address medium-term capacity issues directly but the five focusing steps provide a framework for making these decisions. In the intermediate term, the firm must live with capacity constraints caused by plant and major equipment. The acknowledgement of the need for protective capacity at non-constraints is an aspect of capacity management in TOC that results directly from the relative order of importance of the three measures throughput (T), inventory (I), and operating expense (OE). The fact that T is by far the most important of the three measures leads to the conclusion that the throughput of the constraint should be protected even at the cost of some OE. In the traditional view of capacity, the efficiency of all resources is matched as closely as possible to demand. This approach minimizes OE (because higher capacity resources cost more) while apparently still allowing the system to meet demand. This situation is referred to in TOC as a balanced plant. The flaw in the logic of a balanced plant is that if all resources have exactly the capacity required to meet demand, statistical fluctuations (which are inevitable in any system) will reduce the throughput of the entire system.

2.3.4 Inventory management. The term "inventory" has special significance in TOC for several reasons:

- because inventory is one of the three primary measures in TOC, second in importance only to throughput;
- because the definition of inventory in TOC includes not only what would normally be considered inventory but also anything else the company acquires that can be sold (i.e. money stuck inside the system); and
- because inventory is a primary focus of DBR, the TOC approach to production planning, scheduling, and buffer management.

Goldratt views TOC as a low-inventory rather than a no-inventory system. The main purpose of productive inventory (as opposed to other components of inventory as defined by Goldratt such as property, plant and equipment) is to protect the throughput of the system. Having too much inventory can reduce throughput in a number of ways:

- it makes it physically difficult to move things around;
- it makes it difficult to keep track of things, causing disruptions in production while material is searched for or reproduced because it cannot be found;

- the only way to get too much inventory is to have resources produce more than they should, and if they are producing more than they should they are not available to produce when they need to, in order to support the throughput of the whole system; and
- having too much inventory causes lead-times to be high, resulting in a loss of throughput to customers who need lower lead-times.

On the other hand, if inventory is too low, the throughput of the whole system can be threatened because:

- the constraint resource may starve for material to work on; or
- the shipping schedule may not be met.

Goldratt recommends the use of buffers, primarily in front of the constraint and at shipping, to deal with these potential problems.

The OM literature separates the treatment of inventory into two branches: independent-demand and dependent demand. TOC's approach to dependent-demand inventory is referred to as DBR. DBR is a finite-capacity scheduling method, unlike MRP, which assumes infinite capacity and must be coupled with some kind of capacity check (rough cut capacity planning or capacity requirements planning) to ensure that the resulting schedule is capacity-feasible. In DBR, the constraint resource is scheduled first and material release is back-scheduled from the constraint by the setup and processing times of upstream resources and the time required for processing items in the constraint buffer at the constraint. The assumption is that non-constraint resources will have excess capacity so that queue time at non-constraints will be minimal. This addresses a key issue encountered in MRP systems, namely the problem of estimating lead times for each operation when queue time can be significant at every workstation.

Another key difference between DBR and MRP is in the issue of lot sizes and the use of economic order quantities (EOQ). EOQ models have been a major focus of operations researchers for many years. In TOC, the focus is on maximizing the throughput of the constraint. This has several implications for lot sizing (Jackson *et al.*, 1994; Goldratt, 1990b; Cox *et al.*, 2003). Because items produced are not considered throughput until sold, any lot-sizing rule in TOC would avoid having the constraint work on something that has not been ordered by a customer while there are parts in queue at the constraint that have been ordered by customers. At the same time, the second of the five focusing steps is "exploit the constraint,", i.e. make the best use of the capacity of the constraint, which suggests that minimizing non-productive time on the constraint, including setups, is good. As a result, in a DBR system, lot-for-lot batch sizing would be used but batches would be combined on the constraint to save setups as long as the shipping schedule can be met for any batches delayed at the constraint. At non-constraints, saving setups is not necessary so batches can be worked on a first-come-first-served basis. Cox *et al.* point out that many companies are linking existing MRP systems to DBR in order to improve the utilization of the constraint. They point out that:

> The rope portion of DBR requires a way to perform MRP-like calculations in determining material release timing. An MRP system can be utilized with DBR simply by setting lead times to zero everywhere except the constraint. Constraint lead times are set to the length of the constraint buffer (Cox *et al.*, 2003).

More recently a number of authors (Simatupang *et al.*, 2004) have addressed the TOC approach to independent-demand inventory management in the context of managing the supply chain (Cox *et al.*, 2003, pp. 1071-98 for discussion of the application of strategic buffering, lot sizing, and DBR scheduling in supply chains).

A final characteristic of inventory management in TOC is the distinction between process batches and transfer batches (Jackson *et al.*, 1994; Goldratt, 1990a). A process batch is the number of parts produced between setups, while a transfer batch is the number of parts transferred between processes at one time. Large process batches minimize setups on the constraint while small transfer batches reduce lead time and allow material to flow through the plant. Process batches might be relatively large at the constraint to maximize efficiency there but small at non-constraints because non-constraints have excess capacity and can perform additional setups. Transfer batches can be small throughout the plant to minimize lead times.

In conclusion of this section, we have attempted to show how the methodology construct of TOC comprehends existing OM concepts as summarized in Table I. In the next section we discuss the status of TOC from a theory-development point of view.

3. The theory-development process as applied to TOC

As noted by Lewis (1998), prior to beginning a theory development project, theorists should explicitly state their criteria for a theory and their methods for developing a theory (Bourgeois, 1979; Eisenhardt, 1989). The following quote provides a glimpse of the rationale used by Goldratt (1990a, pp. 23-7) in the development of TOC:

> Each science goes through three quite distinct and radically different stages of development. In each stage every science completely changes its perspective, nomenclature and even its intrinsic premise [. . .] The three stages that every science has gone through are: classification, correlation and effect-cause-effect (emphasis added). [. . .] There are often some practical applications from this (first) stage but the major contribution is usually to create the basic terminology of the subject. The second step – correlation – is usually much more rewarding. It supplies us with procedures that are powerful enough to make some practical predictions about the future [. . .] But the most important stage-the one that is by far more powerful because it enables us to create things in nature-is the stage of effect-cause-effect. Only at this stage is there a widely accepted recognition that the subject is actually a science.

Goldratt (1992) has developed a set of tools, formally known as the thinking processes (current reality tree, evaporating cloud, future reality tree, prerequisite tree and transition tree), for analyzing cause and effect relationships. Davies *et al.* (2005) explore the theoretical underpinnings of the TOC thinking processes by comparing them with existing classificatory frameworks in operational research/management science. Davies *et al.* conclude that the thinking processes "share the ontological and epistemological characteristics and assumptions of extant OR/MS methodologies." In their text book, Cox *et al.* (2003) show excellent examples of the application of the thinking process tools to operations decisions. Although the thinking processes are very powerful methods of developing generic solutions in operations and other areas, we contend that it is the fundamental concepts of TOC that constitute a theory of operations management.

Table II uses MRP, JIT, and TOC as examples of the three stages in the theory-development process. According to Goldratt (1990a), the purpose of science or the theory development process is to identify a minimum number of assumptions that

(1) Classification	*Material requirement planning:* classified data and put it into clearly defined categories brought nomenclature (e.g. bills of material, order files, etc.) improved communication
(2) Correlation	*Just-in-time:* using smaller batches seems to be associated with improved company performance carrying less inventory seems to be associated with improved company performance
(3) Cause and effect	*Theory of constraints* postulates one assumption that the goal of an organization can be measured by a set of three carefully defined operational measures: throughput, inventory and operating expense develops a logical tree that explains many vastly different effects growing from very few basic assumptions

Table II. TOC as a scientific approach

will enable us to explain, by direct logical deduction, the maximum number of natural phenomena. In TOC, one assumption is postulated (i.e. the goal of an organization can be measured by throughput, inventory, and operating expenses), then everything else is derived logically from this assumption and from the fact that constraint(s) limit a system from achieving higher performance.

Other questions that arise in the theory development process are:

- what constitutes, or does not constitute, a theory? (Lewis, 1998; Bourgeois, 1979; Eisenhardt, 1989; Wacker, 1998);
- how should a theory be evaluated? (Whetten, 1989); and
- what are the basic characteristics of an operations management theory? (Schmenner and Swink, 1998). In this section, we address these questions with respect to TOC.

3.1 Components of a good theory

Based on an extensive literature review (Bunge, 1967; Reynolds, 1971; Hunt, 1991), Wacker (1998) concludes that a theory consists of four components (Table III):

(1) definitions of terms or variables;

(2) a domain where the theory applies;

(3) a set of relationships of variables; and

(4) specific predictions.

These components of a theory should be used to judge the precision and limitations of any theory. TOC (1) defines such terms as throughput, inventory, operational expense, and constraint; (2) claims to be applicable to a well-defined, although large, domain; (3) specifies relationships between its variables and terms; and (4) makes specific predictions concerning organizational performance. On this basis, it appears that TOC meets these criteria. Although the components of TOC are not themselves new, it might be argued that TOC has combined them in a way that provides innovative insights into how organizations can be made to operate more effectively. Specifically, Goldratt's focus on constraints has challenged existing assumptions concerning the independence

Table III.
Four basic components of theory as applied to TOC

Component	Theory of constraints
Conceptual definitions	The Goal of any business: "To make money now as well as in the future"
	A constraint: "Anything that limits the performance of a system towards its goal"
	The global operational measures: throughput, inventory and operating expenses
	"Throughput (*T*): the rate at which the system generates money through sales"
	"Inventory (*I*): all the money invested in purchasing things the system intends to sell"
	"Operating expenses: all the money the system spends in turning *I* into *T*"
Domain	Any system with a goal
Relationship building	Net profit (NP) $=$ throughput (T) $-$ operating expenses (OE)
	Return on investment $= (T -$ OE)/inventory
	Productivity $= T$/OE
	Turnover $= T/I$
Predictions	If a plant is perfectly balanced (in terms of its capacity), then *T* will decrease, *I* and OE will increase
	The system's performance is directly related to the performance of the system's constraint
	If the local actions are made to increase *T*, reduce *I* and OE simultaneously, the system will consistently improve its goal of making more money now as well as in the future

of functions and events in complex organizations, and his focus on the need for performance measures that are both local and global challenges existing assumptions that local optima throughout an organization result in global optima. However, while there has been some empirical testing of TOC concepts (Mabin and Balderstone, 2003) and successful applications have begun to appear in OM journals (e.g. the 2003 special issue on TOC in *IJPR*), no major survey-based empirical work has been done to test the theory of TOC as a theory of operations management.

Whetten (1989) suggested a list of criteria in the form of four questions for evaluating theory:

(1) What variables are parts of the theory?

(2) How are the variables related?

(3) Why is selection of the variables and their relationships justified?

(4) Where and when is the theory applicable?

First, TOC brings together numerous operational measures used in practice and redefines them in monetary terms to propose a simple structure of three operational measures: throughput, inventory, and operating expenses. These variables are related to the well-understood financial measures: net profit, return-on-investment, and cash flow. TOC, as applied to OM, also distinguishes between bottleneck and non-bottleneck resources. TOC maintains that the impact of local decisions made to operate (or manage) a bottleneck can be measured in operational terms using cause-and-effect thinking. Swamidass (1991) suggested that Whetten's "why" criterion requires researchers to evaluate why they should give credence to this particular representation of the phenomenon while the "where and when" criterion addresses the question of the generalizability of the theory. TOC's credibility is a major topic of current academic research as well as the main purpose of this paper. Recently, a significant number of research articles and successful case studies have appeared in the OM literature, including textbooks and journal articles (Mabin and Balderstone, 2003; the 2003 special issue on TOC in *IJPR*). TOC's performance measurement system has created the new field of "throughput accounting" which is a topic of current research in accounting (Noreen *et al.*, 1996; Corbett, 1999; Caspari and Caspari, 2004). TOC-based operations management techniques such as DBR, V-A-T analysis, and buffer management have generated interest among academics as well as practitioners. While TOC has primarily been applied to for-profit manufacturing organizations, applications in service industries are also being discussed at conferences and in practitioners' journals. The principles of TOC are also being generalized to demonstrate their applicability to not-for-profit organizations such as churches, schools, and government agencies (Scheinkopf, 1999; Cox *et al.*, 2003).

3.2 Quality of a theory

Lewis (1998) proposes that a theory's quality is predominantly determined by the degree to which it is:

- creative;
- useful; and
- scientific.

Weick (1989) suggests that "creative theories provide novel insights that challenge pre-existing assumptions." Mintzberg (1979) argues that a theory's potential to advance research in a meaningful way, either by linking fragmented research or by providing foundations for future research, demonstrates its usefulness. McCutcheon and Meredith (1993) suggest that scientific theories are created from valid and practical constructs related in a logically consistent manner, enabling empirical testing and possible refutation. With respect to usefulness, TOC could be said to meet Lewis and Mintzberg's criteria, first because it links research from a number of areas, including operations, marketing, economics, and accounting, and second, the large and growing body of research based on TOC is evidence that TOC is providing a foundation for future research (Mabin and Balderstone, 2000). Furthermore, TOC appears to meet McCutcheon and Meredith's criteria for being scientific in that its constructs, such as that of a performance measurement system and an operational decision making process, are practical and related in a logically consistent manner. Goldratt's reinterpretation of the EOQ and the novel insights and solutions derived are a good example of TOC meeting Weick's criteria (Goldratt, 1990a,b; Jackson *et al.*, 1994). In addition, Goldratt's use of novels (Goldratt, 1992, 1994) is a creative approach to the use of narrative to expound the theory of TOC. The TOC thinking processes have been used to explain corporate failures (Gupta *et al.* 2004, Zotov *et al.*, 2004). These novels and cases might be viewed as explanatory case studies, i.e. case studies that have an explanatory purpose rather than just exploratory (Yin, 2003).

3.3 Characteristics of a good operations management theory

Schmenner and Swink (1998) commented on the philosophy of science and the theory development process. They suggested five characteristics to be adhered to by any good operations management theory, which can be used to evaluate TOC as follows:

(1) *The operations management phenomenon for which explanation is sought should be clearly defined. This clarity is enhanced by unambiguous measures …* TOC states that a system's overall performance is limited by the constraint(s) of the system. The system's global goal and the measurements are explicitly defined in terms of throughput, inventory, and operating expenses.
(2) *The description of the phenomenon will likely center on some observed regularities that have been derived either logically or empirically.* TOC rests on two well-known OM concepts, dependency among processes and variability in the processes. TOC views a manufacturing system in terms of the interaction among a combination of constraint and non-constraint resources and logically states that a manufacturing system's overall performance is determined by its constraint resource(s). Is the TOC empirically tested? Mabin and Balderstone (2003) presented an analysis of some empirical evidence, yet this still remains a fertile area of research.
(3) *There should be one or more precise statements of these regularities (laws).* TOC is governed by a set of basic principles or laws (Goldratt, 1990a). Can the precision of these laws be mathematically or empirically tested? This is another fertile research area (Reid and Koljonen, 1999) use a system dynamics-based simulation model to understand the constraint management process and to confirm the identification of the core problem).
(4) *The theory should indicate a mechanism … that explains why the laws work as they do… The theory may include some special terms or concepts that aid the explanation.* TOC and its underlying principles are explained in a very logical and convincing manner in the popular business novel, The Goal, which is probably the first and most widely used business novel in many educational settings. The theory uses a number of special terms and concepts that aid the explanation, e.g. TWT, five-focusing steps for on-going improvement, DBR scheduling, buffer management, and V-A-T analysis. The practitioner literature includes numerous stories of companies making significant improvements by employing TOC, as summarized in Mabin and Balderstone (2003).
(5) *The more powerful the theory, the more likely it will unify various laws and also generate predictions or implications that can be tested with data.* TOC attempts to unify various existing theories and theory-like principles (such as TQM and JIT). It provides an opportunity to generate predictions and hypotheses that can be tested.

The above discussion suggests that TOC has the characteristics of a good theory. Although many aspects of TOC have been extensively discussed and compared to other approaches in operations management journals, the theory of TOC discussed above has yet to be empirically tested.

4. Conclusion

Kuhn, in *The Structure of Scientific Revolutions,* noted that paradigm shifts in science are often accomplished by newcomers to the field adopting new concepts and methods and practitioners of the old paradigm dying off, with little "conversion" of practitioners from the old to the new paradigm. We believe that TOC offers a new paradigm in operations management, one that replaces an over-riding concern for efficiency with achievement of the organization's goal as the primary concern of operations management. We hope that adoption of this new paradigm will involve more conversion and less dying off than many of Kuhn's examples from the history of science. To this end, we have provided in this paper:

- a discussion of the relationships between TOC and traditional OM concepts; and
- an analysis of TOC from the standpoint of theory development.

Our purpose is to demonstrate to those who teach or research in operations management that TOC provides a broad framework for viewing the relationship between operations management and the whole firm, that TOC concepts address many of the traditional concepts of operations management from a more unified perspective, and that a strong argument can be made that TOC is a viable theory of operations management.

Generally, theories are developed from valid, operationalizable constructs related in a logically consistent manner, enabling empirical testing. Review of the literature, data from case studies, and personal assumptions/experiences form the bases of most theory development methods (McCutcheon and Meredith, 1993; Lewis, 1998). In order for TOC to take on the role of a unifying theory of operations management, several things must happen:

- researchers must empirically test the theory of TOC;
- the implications of TOC across the firm, and particularly its impact on other functional areas such as accounting and marketing, must be studied and developed; and
- authors of operations management textbooks must take a broader view of TOC and address a wider variety of operations concepts and issues from a TOC point of view.

Although efforts have been directed to accomplish these goals as pointed out in this paper, a number of research opportunities remain to be exploited in the near future.

Note

1. An exception to the traditional treatment in OM textbooks is *Managing Operations* by Cox *et al.*(2003). A major goal of this textbook is to integrate TOC and the TOC thinking processes with JIT and TQM into a framework "tying strategy to operations through the organization goal, competitive edges and the performance measurement system." Our focus in this paper is more narrow, that is to establish that TOC itself is a theory for operations management.

References

Balderstone, S.J. and Mabin, V.J. (1998), "A review of Goldratt's theory of constraints (TOC): lessons from the international literature", *Proceedings of the 33rd Annual Conference of the Operational Research Society of New Zealand, Auckland*, pp. 205-14.

Blackstone, J.H. (2001), "Theory of constraints – a status report", *International Journal of production Research*, Vol. 39 No. 6, pp. 1053-80.

Blackstone, J.H. and Cox, J.F. (2008), *APICS Dictionary*, 12th ed., Vol. 12, APICS.

Bourgeois, L.L. (1979), "Toward a method of middle range theorization", *Academy of Management Review*, Vol. 4 No. 3, pp. 443-7.

Boyd, L.H. and Gupta, M.C. (2004), "Constraints management: what is the theory?", *International Journal of Operations & Production Management*, Vol. 24 No. 4, pp. 350-71.

Bunge, M. (1967), *Scientific Research 1: The Search for System*, Springer-Verlag, New York, NY.

Caspari, J.A. and Caspari, P. (2004), *Management Dynamics: Merging Constraints Accounting to Drive Improvement*, Wiley, New York, NY.

Chase, R.B. and Tansik, D.A. (1983), "The customer contact model for organization design", *Management Science*, Vol. 29 No. 9, pp. 1037-50.

Chase, R.B., Aquilano, N.J. and Jacobs, F.R. (2006), *Operations Management for Competitive Advantage*, McGraw-Hill, New York, NY.

Cleveland, G., Schroeder, R.G. and Anderson, J.C. (1989), "A theory of production competence", *Decision Sciences*, Vol. 20 No. 4, pp. 655-68.

Corbett, T. (1999), *Throughput Accounting*, North River Press, Croton-on-Hudson, NY.

Cox, J.F. and Spencer, M.S. (1998), *The Constraints Management Handbook*, St. Lucie Press, New York, NY.

Cox, J.F., Blackstone, J.H. and Schleier, J.G. (2003), *Managing Operations: A Focus on Excellence*, North River Press, Great Barrington, MA.

Davies, J., Mabin, V.J. and Balderstone, S.J. (2005), "The theory of constraints: a methodology apart? – a comparison with selected OR/MS methodologies", *Omega: The International Journal of Management Science*, Vol. 33 No. 6, pp. 506-24.

Dettmer, W. (1997), *Goldratt's Theory of Constraints: A Systems Approach to Continuous Improvement*, ASQC Press, Milwaukee, WI.

Ehie, I. and Sheu, C. (2005), "Integrating six sigma and theory of constraints for continuous improvement: a case study", *Journal of Manufacturing Technology Management*, Vol. 16 No. 5, pp. 542-53.

Eisenhardt, K. (1989), "Building theories from case study research", *Academy of Management Review*, Vol. 14 No. 1, pp. 532-50.

Fawcett, S.E. and Pearson, J.N. (1991), "Understanding and applying constraint management in today's manufacturing environments", *Production & Inventory Management Journal*, Third Quarter, pp. 46-55.

Ferdows, K. and DeMeyer, A. (1990), "Lasting improvements in manufacturing performance: in search of a new theory", *Journal of Operations Management*, Vol. 9 No. 2, pp. 168-84.

Flynn, B.B., Schroeder, R.G. and Sakakibara, S. (1994), "A framework for quality management research and an associated measurement instrument", *Journal of Operations Management*, Vol. 11 No. 4, pp. 339-66.

Flynn, B.B., Schroeder, R.G. and Sakakibara, S. (1995), "The impact of quality management practices on performance and competitive advantage", *Decision Sciences*, Vol. 26 No. 5, pp. 659-91.

Flynn, B.B., Sakakibara, S., Schroeder, R.G., Bates, K.A. and Flynn, E.J. (1990), "Empirical research methods in operations management", *Journal of Operations Management*, Vol. 9 No. 2, pp. 250-84.

Fry, T.D., Cox, J.F. and Blackstone, J.H. Jr (1992), "An analysis and discussion of the optimized production technology software and its use", *Production and Operations Management*, Vol. 1 No. 2, pp. 229-42.

Fuchsberg, G. (1992), "Quality programs show shoddy results", *The Wall Street Journal: Eastern Edition*, May 14, pp. B1-B9.

Fuchsberg, G. (1993), "Baldridge award may be losing some luster", *The Wall Street Journal*, April 19, p. B1.

Gardiner, S.C. and Blackstone, J.H. Jr (1994), "The evolution of the theory of constraints", *Industrial Management*, May/June, pp. 13-16.

Goldratt, E.M. (1984), *The Goal*, North River Press, New York, NY.

Goldratt, E.M. (1988), "Computerized shop floor scheduling", *International Journal of Production Research*, Vol. 26 No. 3, pp. 443-55.

Goldratt, E.M. (1990a), *What is this Thing Called Theory of Constraints and how should it be Implemented?*, North River Press, Croton-on-Hudson, NY.

Goldratt, E.M. (1990b), *The Haystack Syndrome: Sifting Information Out of the Data Ocean*, North River Press, Croton-on-Hudson, NY.

Goldratt, E.M. (1992), *It's Not Luck*, North River Press, Croton-on-Hudson, NY.

Goldratt, E.M. (1994), *It's Not Luck*, North River Press, New York, NY.

Goldratt, E.M. (1997), *Critical Chain*, North River Press, Great Barrington, MA.

Goldratt, E.M. and Cox, J. (1984), *The Goal*, North River Press, Croton-on-Hudson, NY.

Goldratt, E.M., Schragenheim, E. and Ptak, C.A. (2000), *Necessary But Not Sufficient*, North River Press, Great Barrington, MA.

Gupta, M.C. (2003), "Constraints management – recent advances and practices", *International Journal of Production Research*, Vol. 41 No. 4, pp. 647-59.

Gupta, M.C., Boyd, L.H. and Sussman, L. (2004), "To better maps: a TOC primer for strategic planning", *Business Horizon*, Vol. 47 No. 2, pp. 15-26.

Hackman, J.R. and Wageman, R. (1995), "Total quality management: empirical, conceptual, and practical issues", *Administrative Science Quarterly*, Vol. 40 No. 2, pp. 309-42.

Handfield, R.B. and Melnyk, S.A. (1998), "The scientific theory-building process: a primer using the case of TQM", *Journal of Operations Management*, Vol. 16 No. 4, pp. 321-39.

Hayes, R.H. and Wheelwright, S.C. (1979), "Link manufacturing process and the product life cycle", *Harvard Business Review*, Vol. 57 No. 1, pp. 133-40.

Heizer, J. and Render, B. (2008), *Operations Management*, 9th ed., Vol. 9, Prentice-Hall, Upper Saddle River, NJ.

Heskett, J.L., Jones, T.O., Loveman, G.W., Sasser, W.E. Jr and Schlesinger, L.A. (1994), "Putting the service profit chain to work", *Harvard Business Review*, Vol. 72 No. 2, pp. 164-74.

Hill, R.C. (1993), "When the going gets rough: a Baldridge Award winner on the line", *The Academy of Management Executive*, Vol. 7 No. 3, pp. 75-9.

Hunt, R. (1991), *Modern Marketing Theory*, Southwest, Cincinnati, OH.

Jackson, G.C., Stoltman, J.J. and Taylor, A. (1994), "Moving beyond trade-offs", *International Journal of Physical Distribution & Logistics Management*, Vol. 24 No. 1, pp. 7-10.

Kendall, G.I. (1998), *Securing the Future: Strategies for Exponential Growth using the Theory of Constraints*, St. Lucie Press, Boca Raton, FL.

Kim, S., Mabin, V.J. and Davies, J. (2008), "The theory of constraints thinking processes: retrospect and prospect", *International Journal of Operations & Production Management*, Vol. 28 No. 2, pp. 155-84.

Krajewski, L.J., Ritzman, L.P. and Malhotra, M.K. (2007), *Operations Management: Processes and Value Chain*, Pearson, Upper Saddle River, NJ.

Lepore, D. and Cohen, O. (1999), *Deming and Goldratt: The Theory of Constraints and the System of Profound Knowledge*, North River Press, Great Barrington, MA.

Lewis, M.W. (1998), "Iterative triangulation: a theory development process using existing case studies", *Journal of Operations Management*, Vol. 16 No. 4, pp. 455-69.

Lockamy, A. and Cox, J.F. (1994), *Reengineering Performance Measurement*, Irwin Professional Publishing, Burr Ridge, IL.

McCutcheon, D.M. and Meredith, J.R. (1993), "Conducting case study research in operations management", *Journal of Operations Management*, Vol. 11 No. 3, pp. 239-56.

Mabin, V.J. and Balderstone, S.J. (2000), *The World of the Theory of Constraints: A Review of the International Literature*, St. Lucie Press, Boca Raton, FL.

Mabin, V.J. and Balderstone, S.J. (2003), "The performance of the theory of constraints methodology: analysis and discussion of successful TOC applications", *International Journal of Operations & Production Management*, Vol. 23 No. 6, pp. 568-95.

Mabin, V.J. and Davies, J. (2003), "A framework for understanding the complementary nature of TOC frames: insights from the product mix dilemma", *International Journal of Production Research, Special Issue on Constraints Management*, Vol. 41 No. 4, pp. 661-80.

Meredith, J.R., Raturi, A., Amoako-Gyampaeh, K. and Kaplan, B. (1989), "Alternative research paradigms in operations", *Journal of Operations Management*, Vol. 8 No. 4, pp. 297-326.

Mintzberg, H. (1979), "An emerging strategy of 'direct' research", *Administrative Science Quarterly*, Vol. 24 No. 4, pp. 582-9.

Noreen, E., Smith, D. and Mackey, J. (1996), *The Theory of Constraints and its Implications for Management Accounting*, North River Press, Great Barrington, MA.

Pannirselvam, G.P., Ferguson, L.A., Ash, R.C. and Siferd, S.P. (1999), "Operations management research: an update for the 1990s", *Journal of Operations Management*, Vol. 18 No. 1, pp. 95-112.

Rahman, S. (1998), "Theory of constraints: a review of the philosophy and its applications", *International Journal of Operations & Production Management*, Vol. 18 No. 4, pp. 336-55.

Reid, R.A. and Koljonen, E.L. (1999), "Validating a manufacturing paradigm: a system dynamics modeling approach", *Proceedings of the Winter Simulation Conference*, pp. 759-65.

Reynolds, P.D. (1971), *A Primer in Theory Construction*, Macmillan, New York, NY.

Ronen, B. and Pass, S. (1994), "Focused management: a business-oriented approach to total quality management", *Industrial Management*, Vol. 36 No. 3, pp. 9-12.

Ronen, B. and Pass, S. (2007), *Focused Operations Management: Achieving More with Existing Resources*, Wiley, San Francisco, CA.

Ronen, B. and Starr, M.K. (1990), "Synchronized manufacturing as in OPT: from practice to theory", *Computers & Industrial Engineering*, Vol. 18 No. 4, pp. 585-600.

Rucci, A.J., Kirn, S.P. and Quinn, R.T. (1998), "The employee-customer profit chain at Sears", *Harvard Business Review*, Vol. 76 No. 1, pp. 83-97.

Scheinkopf, L.J. (1999), *Thinking for a Change: Putting the TOC Thinking Processes to Use*, St. Lucie Press, Boca Raton, FL.

Schmenner, R.W. and Swink, M.L. (1998), "On theory in operations management", *Journal of Operations Management*, Vol. 17 No. 1, pp. 97-113.

Schroeder, R. (2008), *Operations Management*, McGraw-Hill/Irwin, New York, NY.

Simatupang, T. and White, A. (1998), "A policy resolution model for knowledge acquisition in quality management", *Total Quality Management*, Vol. 9 No. 8, pp. 767-79.

Simatupang, T.M., Wright, A.C. and Sridharan, R. (2004), "Applying the theory of constraints to supply chain collaboration", *Supply Chain Management*, Vol. 9 No. 1, pp. 57-70.

Skinner, W. (1969), "Manufacturing – missing link in corporate strategy", *Harvard Business Review*, Vol. 47 No. 3, pp. 136-45.

Slack, N., Chambers, S. and Johnston, R. (2006), *Operations Management*, 5th ed., FT/Prentice-Hall, London.

Spencer, M.S. and Cox, J.F. (1995), "Optimum production technology (OPT) and the theory of constraints (TOC): analysis and genealogy", *International Journal of Production Research*, Vol. 33 No. 6, pp. 1495-504.

Srikanth, M.L. and Robertson, S.A. (1995), *Measurements for Effective Decision Making*, Spectrum, Wallingford, CT.

Stein, R.E. (1994), *The next phase of total quality management: TQM II and the focus on profitability*, Marcel Dekker, New York, NY.

Stevenson, W.J. (2007), *Operations Management*, 9th ed., McGraw-Hill/Irwin, New York, NY.

Sullivan, T.T., Reid, R.A. and Cartier, B. (2007), *The Theory of Constraints International Certification Organization Dictionary*, 1st ed., available at: www.tocico.ort/14a/pages/index.cfm?pageid = 3331 (accessed February 15, 2008).

Swamidass, P.M. (1991), "Empirical science: new frontier in operations management research", *Academy of Management Review*, Vol. 16 No. 4, pp. 793-814.

Umble, M. and Srikanth, M. (1997), *Synchronous Management: Profit Based Manufacturing for the 21st Century*, Vols I and II, Spectrum, Guilford, CT.

Vickery, S.K. (1991), "A theory of production competence revisited", *Decision Sciences*, Vol. 22 No. 3, pp. 635-43.

Wacker, J.G. (1998), "A definition of theory: research guidelines for different theory-building research methods in operations management", *Journal of Operations Management*, Vol. 16 No. 4, pp. 361-85.

Watson, K.J., Blackstone, J.H. and Gardiner, S.C. (2007), "The evolution of a management philosophy: the theory of constraints", *Journal of Operations Management*, Vol. 25 No. 2, pp. 387-402.

Weick, K.E. (1989), "Theory construction as disciplined imagination", *Academy of Management Review*, Vol. 14 No. 4, pp. 516-31.

Westbrook, R. (1994), "Priority management: a new theory for operations management", *International Journal of Operations & Production Management*, Vol. 14 No. 6, pp. 4-24.

Westbrook, R. (1995), "Action research: a new paradigm for research in productions and operations management", *International Journal of Operations & Production Management*, Vol. 15 No. 12, pp. 6-20.

Whetten, D. (1989), "What constitutes a theoretical contribution?", *Academy of Management Review*, Vol. 14 No. 4, pp. 490-5.

Wilkinson, A., Redman, T. and Snape, E. (1995), "New patterns of quality management in the United Kingdom", *Quality Management Journal*, pp. 37-49, Winter.

Yin, R.K. (2003), *Case Study Research: Design and Methods*, 3rd ed., Vol. 5, Sage Publications, Thousand, CA.

Zbaracki, M.J. (1998), "The rhetoric and reality of Total Quality Management", *Administrative Science Quarterly*, Vol. 43 No. 3, pp. 602-36.

Zotov, D., Hunt, L. and Wright, A. (2004), "Analysing systemic failure with the theory of constraints", *Human Factors and Aerospace Safety*, Vol. 4 No. 4, pp. 321-54.

Further reading

McMullen, T. Jr (1998), *Introduction to the Theory of Constraints (TOC) Management System*, St. Lucie Press, Boston, MA.

Meredith, J.R. and Shafer, S.M. (2007), *Operations Management for MBAs*, Wiley, New York, NY.

Skinner, W. (1974), "The focused factory", *Harvard Business Review*, Vol. 52 No. 3, pp. 113-21.

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