Available online at www.sciencedirect.com
ScienceDirect
Journal of Operations Management 25 (2007) 387–402
JOURNAL OF OPERATIONS MANAGEMENT
www.elsevier.com/locate/jom

The evolution of a management philosophy: The theory of constraints

Kevin J. Watson [a,*], John H. Blackstone [b,1], Stanley C. Gardiner [c,2]

[a] University of New Orleans, College of Business Administration, New Orleans, LA 70148, United States
[b] University of Georgia, Terry College of Business, Athens, GA 30601, United States
[c] California State University at Chico, College of Business, Chico, CA 95929, United States

Abstract

In 2004, the Theory of Constraints celebrated its Silver Anniversary. In twenty-five years, what started out as a scheduling software has evolved into a management philosophy with practices and principles spanning a multitude of operations management subdisciplines. As the Theory of Constraints has grown, so has its acceptance by both practitioners and academicians. At this point in its development, as it transitions from niche to mainstream, it is important to review what has been accomplished and what deficiencies remain so that both the promise and problems impeding greater acceptance can be examined. To that end, we review the evolution of principal TOC concepts and practices in an objective fashion.

Keywords: Theory of constraints; Accounting/operations interface; Manufacturing control systems; Operations strategy

1. Introduction

In 1979, development of the Theory of Constraints (TOC) management philosophy began with the introduction of Optimized Production Timetables scheduling software (Goldratt and Cox, 1984). TOC has evolved from this simple production scheduling software program into a suite of integrated management tools encompassing three interrelated areas: logistics/production, performance measurement, and problem solving/thinking tools (Spencer and Cox, 1995). Due to its simple yet robust methodology, application of TOC techniques have been discussed in the academic literature and popular press across a variety of operations management subdisciplines, including: project management (Goldratt, 1997; Leach, 1999; Umble and Umble, 2000; Steyn, 2001; Cohen et al., 2004), retailing (Gardiner, 1993; Goldratt, 1994), supply chain management (Rahman, 2002; Watson and Polito, 2003; Simatupang et al., 2004), process improvement (Schragenheim and Ronen, 1991; Atwater and Chakravorty, 1995; Gattiker and Boyd, 1999), and in a variety of production environments (Jacobs, 1983; Koziol, 1988; Lambrecht and Segaert, 1990; Raban and Nagel, 1991).

Studies reporting anecdotal evidence from early adopters suggested that TOC techniques could result in increased output while decreasing both inventory and cycle time (Aggarwal, 1985; Johnson, 1986; Koziol, 1988). Rigorous academic testing has validated those early findings revealing that manufacturing systems employing TOC techniques exceed the performance of

---

* Corresponding author. Tel.: +1 504 280 3121.
E-mail addresses: KWatson@uno.edu (K.J. Watson), JBlackst@terry.uga.edu (J.H. Blackstone), SGardiner@csuchico.edu (S.C. Gardiner).
[1] Tel.: +1 706 542 3718.
[2] Tel.: +1 530 898 6747.

0272-6963/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.jom.2006.04.004

those using Manufacturing Resource Planning (MRP), Lean Manufacturing, Agile Manufacturing, and Just-in-Time (JIT) (Ramsay et al., 1990; Fogarty et al., 1991; Cook, 1994; Holt, 1999; Mabin and Balderstone, 2000). The results of these studies indicate that TOC systems produce greater levels of output while reducing inventory, manufacturing lead time, and the standard deviation of cycle time.

TOC techniques have been applied at a number of Fortune 500 companies; 3M, Amazon, Boeing, Delta Airlines, Ford Motor Company, General Electric, General Motors, and Lucent Technologies have publicly disclosed significant improvements achieved through deployment of TOC solutions. Additionally, a number of adopting companies state an unwillingness to disclose improvements for competitive reasons. Application of TOC is not limited to for-profit companies; not-for-profit organizations and government agencies such as Habitat for Humanity, Pretoria Academic Hospital, British National Health Service, United Nations, NASA, United States Department of Defense (Air Force, Marine Corps, and Navy), and the Israeli Air Force all have successfully employed TOC solutions.

However, despite mounting evidence in both the academic literature and popular press of the potential benefits of TOC implementation, mainstream acceptance has proven elusive. According to the 2003 Census of Manufacturers less than 5% of U.S. manufacturing facilities drive process improvement efforts with TOC (IW/MPI, 2003). Additionally, TOC implementations appear to be the least mature of the various methodologies employed with only one of the 42 facilities employing TOC reporting completion of the transformation process.

We have undertaken this research project to better understand both the promise of TOC and the problems that impede its widespread acceptance. We do not intend this to be a literature review, although we will reference a plethora of academic articles. Rather we intend to discuss the evolution of principal TOC concepts and practices in an objective fashion. To clearly focus on the development of principal TOC concepts, we have segmented the evolution of TOC into five eras, Fig. 1:

1. The *Optimized Production Technology* Era – the secret algorithm.
2. *The Goal* Era – articulating drum-buffer-rope scheduling;
3. *The Haystack Syndrome* Era – articulating the TOC measures.
4. The *It's Not Luck* Era – thinking processes applied to various topics.
5. The *Critical Chain* Era – TOC project management.

Defining the eras in terms of the titles of Dr. Goldratt's books does not imply that he has been the sole contributor to the evolution of TOC. Indeed, we identified 400+ books, articles, dissertations, conference proceedings, reports, etc. that contribute to the body of knowledge. Additionally, it is understood that practitioners have made numerous undocumented advances within the many companies that have adopted TOC. However, Dr. Goldratt's books serve as useful demarcations in time, allowing us to analyze the principal events and developments during each era. Discussion of the five eras is followed by an examination of deficiencies in the TOC literature. This examination is intended to point to areas that, once addressed, will facilitate acceptance of TOC by a wider audience. We conclude with a discussion of what appears to be the emergence of a sixth TOC era; this includes a review of emerging applications and suggestions for future research.

2. Era 1: optimized production technology

The Theory of Constraints has an unspectacular beginning, resulting not from some grand vision of production management's future but from a simple request for help. Late in the 1970s, a neighbor of Dr.

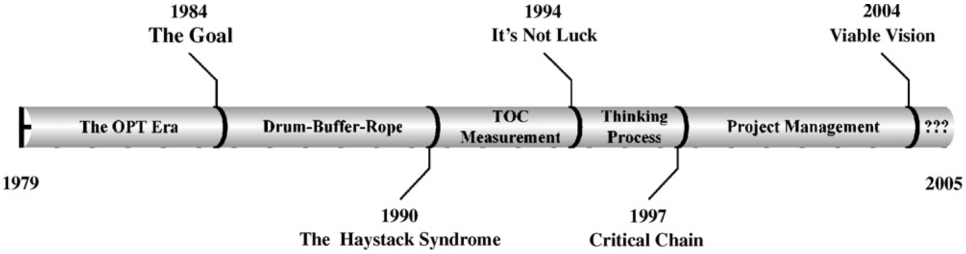
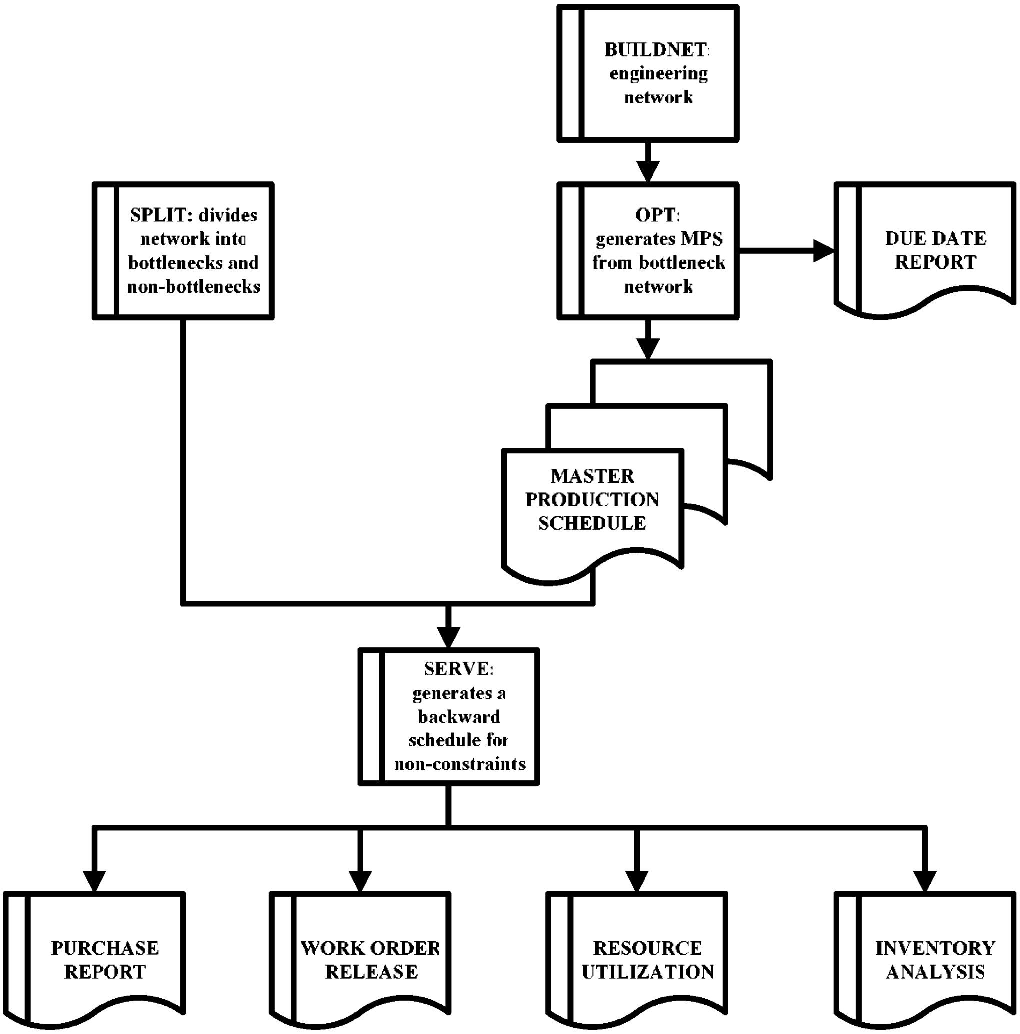


Fig. 1. Timeline of major eras in the development of TOC.

Eliyahu Goldratt operated a plant that produced chicken coops (Bylinski, 1983). The neighbor asked Goldratt, a physicist, for assistance in developing a scheduling program to increase output. Goldratt responded by developing a program that tripled the plant's output within a short period of time.

In 1980, Goldratt introduced that solution, Optimized Production Timetables – later renamed Optimized Production Technology or OPT, in the United States when he delivered a paper to the APICS International Conference (Goldratt, 1980). The program, first described in the academic literature by Fry et al. (1992), consists of four major components: BUILDNET, SERVE, SPLIT, and OPT (originally called BRAIN). OPT and SERVE contain the actual algorithm used for scheduling production while BUILDNET and SPLIT collect and arrange data in the required format. Organization of data in BUILDNET allows OPT to efficiently generate master production schedules for bottleneck locations (Goldratt, 1988b). Based on the constraint schedule, the SERVE module backward schedules production at non-bottleneck locations and determines the release of non-constraint materials. The function and relationship between the modules, Fig. 2, is elaborated on by Bond (1993). Additionally, Goldratt (1988b) furnishes an excellent accounting of the evolution of his thinking during the OPT era.



Adapted from: Bond, T.C. *An investigation into the use of OPT production scheduling.* Production Planning & Control, 1993. 4(4): p. 399.

Fig. 2. The OPT modules.

OPT was quickly adopted by a number of major corporations. Three years following introduction, Bylinski (1983) reported several successful OPT implementations, including two General Electric plants. In the September/October 1985 Harvard Business Review, Aggarwal reported that 100 companies worldwide had purchased OPT at a minimum price of $2 million. However, with success came failure, as several plants experienced problems implementing OPT. Investigating implementation failures lead Dr. Goldratt to the underlying core problem, lack of understanding with regard to how OPT schedules are produced.

At its introduction, OPT schedules were controversial because they kept some stations efficiently busy while others were idle at times. This contradicted the performance measurement system in place at most U.S. plants, as workers were usually measured by individual efficiency. Therefore, workers would sometimes ignore the schedule and produce parts for inventory in an attempt to stay busy and avoid unfavorable performance appraisals. These actions created unsynchronized material flows through the plant, scrambling the schedule and endangering the success of OPT itself. To combat this behavior, Goldratt decided to educate managers and workers addressing first the fallacy of efficiency as the prime measure of worker productivity. As part of his initial efforts, Goldratt released the nine OPT rules, Table 1 (Goldratt and Fox, 1986). Rule number three states ''Utilization and activation of a resource are not the same''; underscoring management's need to address performance measurement as part of OPT implementation. The principal tenet of TOC is that within each system at least one constraint exists that limits the ability of the system to achieve higher levels of performance relative to its goal. Maximum utilization of the constraint therefore should lead to maximum output from the system. However, to compel activation of non-constraint resources at 100% of their capacity does not increase output, it only serves to create excess inventory. The remaining OPT rules underscore the preceding point.

While Goldratt's attempts to educate managers and worker would yield results by providing the impetus for publication of *The Goal*, incongruence between OPT schedules and the performance measurement system was not the only controversial aspect of OPT. Creative Output, the company that initially marketed OPT, attempted to protect the proprietary algorithms by installing OPT in a tamper-proof box so that the only output the plant received was a schedule (Bylinski, 1983). Thus, the manner in which OPT was initially packaged contributed to the lack of understanding with regard to how schedules were produced. This veil of secrecy was pierced following a failed implementation at M&M Mars Company, who filed suit against Creative Output and sought the release of the OPT algorithms in an effort to prove its assertion that Creative Output should have realized that OPT was an inappropriate solution for their specific situation and could not have deliver the promised benefits. This matter was settled; however, the lawsuit combined with Goldratt's departure from Creative Output shortly thereafter to concentrate on management education and concept development tarnished TOC in the eyes of many. However, it should be noted that following Goldratt's departure, the software enterprise moved to England where Goldratt's brother continued to successfully market OPT and other TOC-based software products as Scheduling Technologies Group. Manugistics acquired Scheduling Technologies in January 2001, and continues to sell various TOC based software solutions to this day.

3. Era 2: the goal

Despite repeated attempts to draw attention to the efficiency fallacy (Goldratt, 1981, 1983), reaction by practitioners was muted. Goldratt states that his points

Table 1
The nine OPT rules

1. Balance flow, not capacity.
2. Level of utilization of a non-bottleneck is determined not by its own potential but by some other constraint in the system.
3. Utilization and activation of a resource are not synonymous.
4. An hour lost at a bottleneck is an hour lost for the total system.
5. An hour saved at a non-bottleneck is just a mirage.
6. Bottlenecks govern both throughput and inventory in the system.
7. A transfer batch may not, and many times should not, be equal to the process batch.
8. The process batch should be variable, not fixed.
9. Schedules should be established by looking at all of the constraints simultaneously. Lead times are a result of a schedule and cannot be predetermined.

Adapted from: Goldratt, E.M. and R.E. Fox, *The Race*. 1986, Croton-on-Hudson, NY: North River Press.

‘‘were not a revelation’’ to managers; however, despite agreement with the argument there was not a groundswell to remove efficiency measures. Failing to elicit a response through presentations at industry meetings, Goldratt changed tactics. In 1984, he and Jeff Cox wrote *The Goal*, a manufacturing novel in which the protagonist, Alex Rogo, saves his plant with the help of some pointed questions by his mentor, Jonah. *The Goal* was written largely to educate workers at facilities employing OPT in an effort to have them follow OPT schedules; however, it became a business best seller with numerous companies attempting to implement the concepts found in the book.

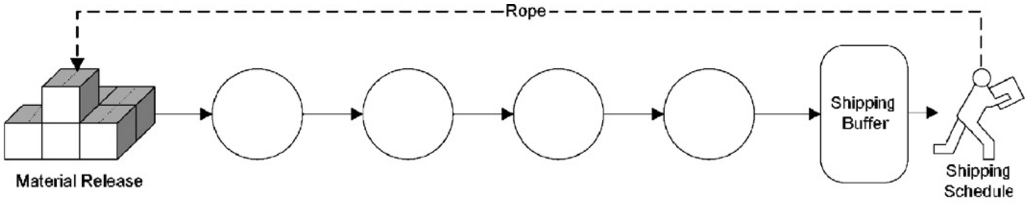
The Goal describes a number of heuristics and techniques that have become the foundation for TOC practice. At its most basic, *The Goal* outlines the Five Focusing Steps (5FS), the process by which TOC concepts are implemented. The 5FS have evolved into what is now called the Process Of OnGoing Improvement (POOGI), an amalgamation of the Five Focusing Steps and the two prerequisites for implementation. The first prerequisite for implementation is to define the system under investigation and identify its purpose. Having defined the purpose of the system, the second prerequisite is to define measurements that align the system to that purpose.

The first of the Five Focusing Steps is to identify the constraint. Identification of the constraint follows from the principal tenet of TOC, ‘‘constraints determine the performance of a system.’’ Since there are few constraints in any system, management of these few key points allows for effective control of the entire system. Once the constraint has been identified, the next step is to determine the most effective means to exploit it. Exploitation of the constraint seeks to achieve the highest rate of throughput possible within the confines of the system’s current resources. The output of the system is limited by the rate of throughput at the constraint; therefore, the third step is to subordinate the system to the constraint. This eliminates waste and insures maximum responsiveness since the system only works on that which it can reasonably expect to turn into cash through sales in the near term. Should additional output be necessary, the fourth step elevates throughput by adding capacity to the system at the constraint location. Finally, the fifth step renews the improvement cycle by stating ‘‘if in the previous steps a constraint has been broken, start over; do not let inertia set in.’’

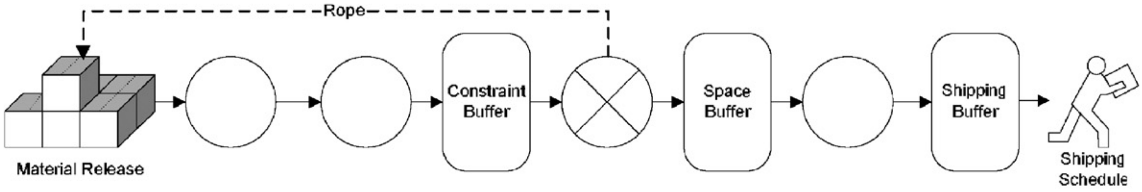
Flowing directly from the Five Focusing Steps, *The Goal* develops the scheduling methodology employed under TOC: drum-buffer-rope (DBR). This technique, which derives its name from metaphors developed in *The Goal* and spelled out in *The Race*, has been well defined in the literature (Goldratt and Fox, 1986; Lambrecht and Decaluwe, 1988; Schragenheim and Ronen, 1990; Gardiner et al., 1993; Umble and Srikanth, 1995). The constraint, or drum, determines the pace of production. The rope is the material release mechanism; releases material to the first operation at a pace determined by the constraint. Material release is offset from the constraint schedule by a fixed amount of time, the buffer. Buffers are strategically placed to protect shipping dates and to prevent constraint processes from starvation due to a lack of materials. The arrangement in a typical DBR system is shown in Fig. 3.

Consistent with the step one of the Five Focusing Steps, identification of the drum, or constraint, is required for implementation of a DBR system. According to the APICS Dictionary, a constraint is ‘‘any element or factor that prevents a system from achieving a higher level of performance with respect to its goal’’ (Blackstone and Cox, 2004). While constraints generally take one of three forms: physical (resource capacity less than demand), market (demand less than resource capacity), and policy (formal or informal rules that limit productive capacity of the system); DBR is intended to address market or physical constraints. Having identified the constraint, the objective for scheduling becomes to synchronize production with customer requirements (Perez, 1997).

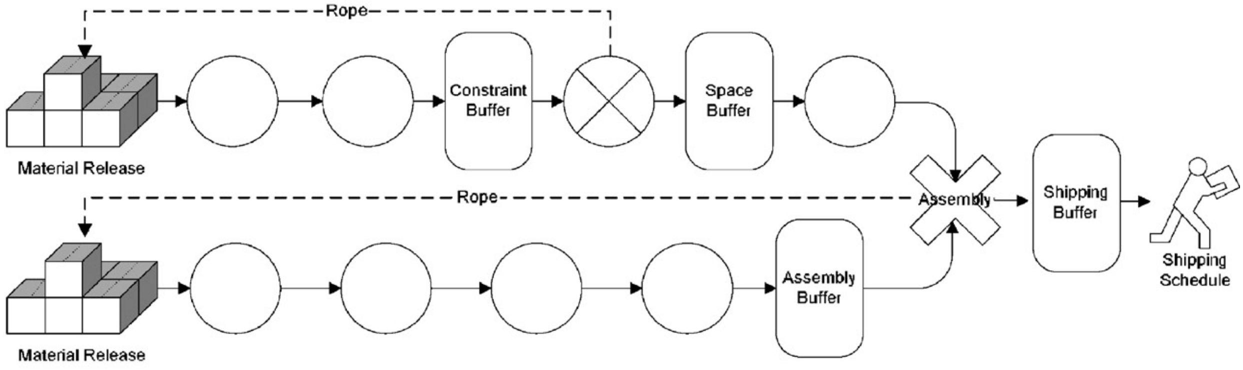
The second step of the 5FS, exploit the constraint, necessitates strategic buffering at the constraint and at other system control points to protect the ability of the system to produce the schedule (Schragenheim and Ronen, 1991). The term ‘‘buffers’’ is often synonymous with work-in-process or finished goods inventory; however, TOC makes use of three distinct buffer types: time, shipping, and capacity. Time buffers offset the release of raw materials by the protection or buffer time allowed. The amount of work-in-process inventory in the system is the physical representation of the amount of protection allotted to a critical resource as measured by time. Shipping buffers maintain a small amount of finished good inventory used to protect due date performance (Umble and Srikanth, 1995). Further, shipping buffers increase responsiveness to market demand by allowing the system to deliver an item in less than the manufacturing lead time. Capacity buffers exist in a TOC system to the extent that non-constrained resources have extra capacity. Capacity buffers help to maintain the time and shipping buffers during periods in which the processes experience fluctuations in output,



(a) Product line with market constraint



(b) Product line with capacity constraint



(c) Product line with assembly of non-constraint parts to constraint parts

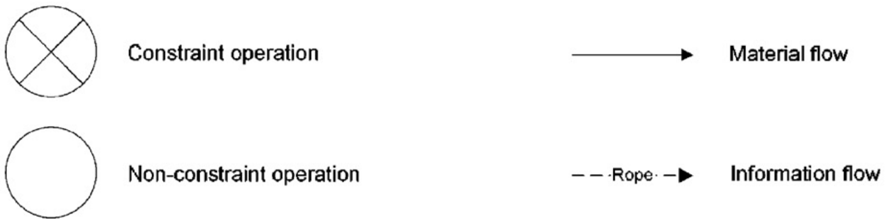


Fig. 3. Typical drum-buffer-rope configurations.

as downtime at non-constraint machine can be made up before adversely impacting the schedule.

Finally, consistent with step three of the 5FS, the rope subordinates non-constraint machines to the constraint, releasing inventory to the production system based on the rate of consumption at the constraint. The ‘‘length’’ of the rope, hence the amount of inventory in the system, is determined by the protection to the constraint provided by the buffer. Since work-in-process inventory downstream of the constraint is negligible (Hopp and Spearman, 2000), the rope acts to keep minimal and constant inventory levels in the system. Therefore, TOC systems exhibit reduced and consistent lead times when compared to traditional management techniques.

Buffer management is a related TOC application that assists in managing tradeoffs between protection of the constraint and lead times. This is necessary since increasing buffer size increases the amount of protection for the constraint; however, releasing material earlier, increases both WIP and lead time. Buffer management serves two additional purposes (Schragenheim and Ronen, 1990, 1991). First, it allows management to identify possible problems in the manufacturing system before they impact the schedule. Comparison of actual versus planned buffer size at set times during the manufacturing schedule allows managers to spot problems prior to the point at which they becomes critical, and, through quick feedback to the problem work center, reduce unnecessary expediting. Second, buffer management can be used to focus improvement efforts on those processes that have the greatest negative impact on schedule performance, simplifying the management of continuous improvement activities. Buffer management also allows managers to assess process improvements as they are implemented.

As previously stated, rigorous testing of DBR indicates that TOC systems produce greater numbers of product while reducing inventory, manufacturing lead time, and the standard deviation of cycle time. However, continued implementation problems created in part by the incongruence between the TOC philosophy and traditional performance measurement systems returned Goldratt's attention to the issue of measurement.

4. Era 3: the haystack syndrome

From early in its development, TOC advocates have campaigned for reform of the standard absorption cost accounting system. This campaign was initiated at the 1983 International APICS Conference when Goldratt proclaimed that "cost accounting is public enemy number one to productivity" (Goldratt, 1983). According to Goldratt, cost accounting principles when applied to local performance measurement, product cost, and capital investment decisions provide misleading or incorrect information to decision makers, which may cause implementation of policies or practices that are incongruent with company goals. Advocates of reform state that traditional cost accounting suffers from antiquated assumptions that no longer fit highly flexible manufacturing systems. As stated by Smith (2000), "the theory behind financial accounting is valid for the purpose of reporting past activities; however, the actions necessary to maximize throughput and cash flow now and in the future are not the same as minimizing local unit cost and maximizing short-run reported net income" (p. 44). As such, its continued use for internal reporting and control is increasingly inappropriate in competitive global markets with numerous nimble competitors. While based on different philosophical underpinnings, Kaplan and Johnson reached similar conclusions, independent of Goldratt, as they developed Activity-based Costing (Kaplan, 1983, 1984, 1986; Johnson and Kaplan, 1987).

Faced with continued incongruence between TOC and cost accounting, Goldratt published two manuscripts (Goldratt, 1988a, 1990) that incited renewed interest among TOC proponents in overhauling the cost accounting framework. His work, along with that of others (Fry and Cox, 1989; Weston, 1991; Fry, 1992; Lockamy and Cox, 1994; Srikanth and Robertson, 1995; Cox et al., 1998; Lockamy and Spencer, 1998; Smith, 2000), lead to the development of a process-focused performance measurement system which focuses the organization on actions that improve overall financial performance. This framework, called Throughput Accounting (TA), consists of nine interrelated measurements for use at various organizational levels which have been shown to be valid in the context of economic theory (Fry, 1992; Spencer, 1994).

The overriding goal in a TOC system is to make money now and in the future. In order to ascertain whether an organization is obtaining that goal, three global performance measures are utilized: Net Profit (NP), Return on Investment (ROI), and Cash Flow (CF). While TOC makes use of these traditional measures for global performance; Goldratt (1983) states that they are not applicable at the subsystem level. To bridge the gap between corporate financial measurements and business unit/plant level measurement, Goldratt and Cox (1984) introduce three plant level performance measurements: throughput (T), inventory (I), and operating expense (OE). The plant level measurements reinforce the goal of maximizing corporate profits by emphasizing revenue generation while simultaneously reducing inventory and operating expense (Cox et al., 1997). The plant level measures do not translate directly to the process level; therefore, as alternatives to the traditional measure of efficiency, Goldratt (1988a) introduces three process level measures: throughput dollar days (T$D), inventory dollar days (I$D), and local operating expense.

While many of these terms are familiar, unique application and definitions distinguish them in the context of TOC. The first and perhaps most important difference is based on a philosophical difference between TOC and traditional accounting. While TOC considers cost reduction important, the focus is on increasing throughput; therefore, OE in TOC plants is not stressed to the extent that would be found in a traditional environment. Second, TA is conservative in terms of recognizing throughput; revenue is recognized only when a sale to the consumer, not a downstream member of the supply chain, has taken place (Noreen et al., 1995). Third, material inventories, regardless of state of completion, are carried at the raw material purchase price providing a disincentive to produce "apparent profits," paper profits that result from delayed recognition of some expenses under traditional accounting until the sale of inventory occurs (Noreen et al., 1995; Corbett, 1998). A fourth distinguishing factor of TA is the treatment of operating expense as fixed during a specific, usually short, period of time. This is done to prevent dissemination of misleading or incorrect information based on the allocation of indirect or non-variable costs. Finally, TA provides for different measures for constraint and non-constraint machines. While adherence to schedule and efficiency are appropriate measures of constraint performance, full production at non-constraints serves only to create excess inventory. Dollar day measures address this by subordinating non-constraint resources to the constraint schedule.

Beyond the nine measures, perhaps the most important TA concept is contribution per constraint minute (CPCM) (Gardiner and Blackstone, 1991). Fox (1987) introduces CPCM in the context of the PQ problem, so named for the two products used in the original example. The PQ problem addresses cost accounting's failure to identify the disproportionate impact of the constraint by calculating the opportunity cost of production of a particular product at the constraint, providing a reliable measure for exploitation of the constrained resource. The widest application of PQ, and CPCM, is to the make-or-buy decision; however, it has also been used to (1) determine retail product mix based on opportunity cost of limited shelf space (Gardiner, 1993), (2) identify strategic linkages between the operations and purchasing functions (Low, 1993), (3) direct preventative maintenance efforts (Chakravorty and Atwater, 1994; Atwater and Chakravorty, 1995), and (4) prioritize set up time improvement efforts (Chakravorty and Sessum, 1995). Additionally, a number of authors have utilized PQ to compare decision-making under TA and traditional accounting practices. Boyd and Cox (2002) is perhaps the most compelling comparison to date, showing that throughput accounting consistently produces optimal decisions while traditional cost accounting, direct costing, and activity based costing generally produce suboptimal decisions.

TOC measurements continue to evolve. Srikanth and Robertson (1995), state that appropriate measurement systems must capture internal costs of production (TIOE) and external customer satisfaction. To that end, they introduce a merger between throughput accounting and the Balanced Scorecard^{TM}. The argument for this approach is clear, TA is sufficient for directing activities within a company. However, to direct increases in throughput, management must have measures of customer satisfaction and competitive position. This call to include customer satisfaction data has been adopted by Alber and Walker (1998) who establish several definitions of TOC measurements for application in the realm of supply chain management. While many of their definitions modify the traditional TIOE measures; several new measures capturing customer service levels at critical points within the supply chain are introduced.

There are clear indications that the traditional accounting community has taken notice. In November 2004, the Financial Accounting Standards Board issued Statement 151, the first substantial change to inventory costing in 50 years. According to John Caspari, this change, while minor represents an opportunity for future compatibility between the traditional and throughput accounting communities. Additionally, the Institute for Management Accountants in conjunction with Arthur Andersen issued Statement 4HH in 1999, which in part stated:

> "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." (IMA, 1999, p. 1)

5. Era 4: it's not luck

In 1994, Goldratt published *It's Not Luck*. In keeping with his preference for the Socratic Method and directed self discovery, *It's Not Luck* was not a cookbook for implementation of generic TOC solutions; rather it presents a roadmap for discovering novel solutions to complex unstructured problems: the Thinking Processes (TP). While *The Goal* clearly identifies management policies as a significant source of potential constraints, most academicians believed TOC to be synonymous with drum-buffer-rope. Therefore, despite the fact that the first TP tools were developed in 1987, became part of the curriculum of Jonah courses offered through the Goldratt Institute as early as 1988, and became the emphasis of those courses by 1992 (Noreen et al., 1995); this introduction of the logic tools came somewhat as a surprise to many.

The TP tools provide a rigorous and systematic means to address identification and resolution of unstructured business problems related to management policies (Schragenheim and Dettmer, 2000). The TP tools are comprised of two logic categories, sufficient cause or effect-cause-effect logic which underlies the current reality tree (CRT), future reality tree (FRT), and transition tree (TT) and necessary condition logic which is utilized by the evaporating cloud (EC) and prerequisite tree (PRT) to surface hidden assumptions that prevent identification of effective solutions to specific core problems (Scheinkopf, 1999). The application tools are interrelated, in that output from one is used as input to one or more others as shown in Fig. 4.

Application of the TP tools generally begins with identification of the core problem(s) through the development of the CRT. An enhancement to the traditional method allows core problems to be derived from what is called the three cloud method, which begins with the creation of three evaporating clouds. Commonality in the cloud elements allows for the production of the core conflict cloud (CCC). The CCC provides significant insight to the underlying conflict, simplifying production of the CRT (Button, 1999, 2000;

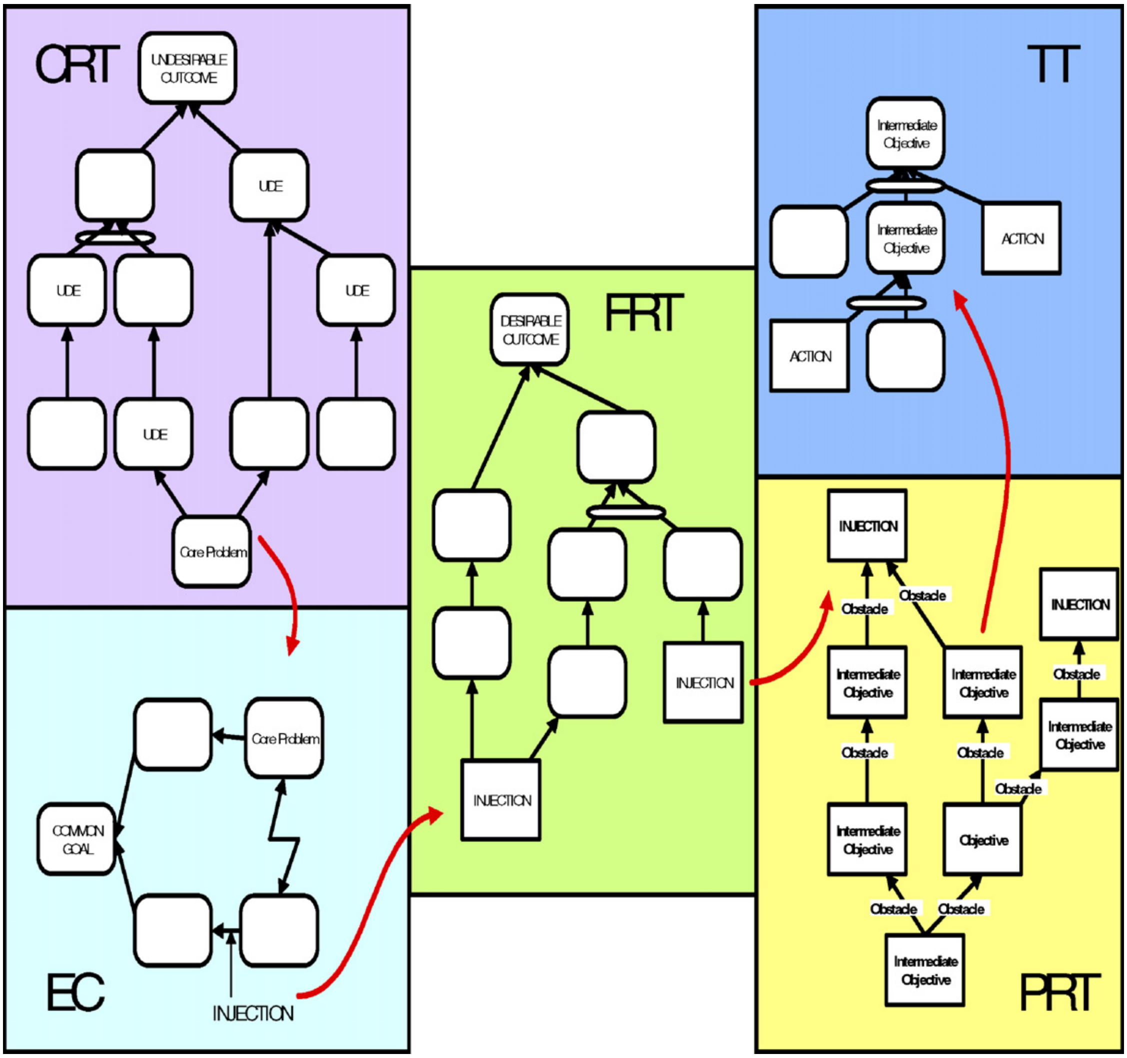


Fig. 4. The TOC thinking process application tools.

Smith, 2000; Chaudhari and Mukhopadhyay, 2003; Reid and Cormier, 2003). A related application is the eight question storyline approach (Cox et al., 2003, 2005), which facilitates EC construction by requiring answers to generic questions that clarify the situation and focus the tool on underlying problems.

Once the core problems have been identified, evaporating clouds allow for the discovery of hidden assumptions that are invalid or can be invalidated by some future action, called injections, which form the basis to successful problem resolution. The solution is tested by means of the FRT to insure that Negative Branches, or unexpected negative outcomes, will not result from implementation of the proposed solution. Once the solution has been validated, the injection becomes the objective of the PRT which identifies intermediate objectives that must be achieved in order to overcome obstacles to successful implementation of the solution. Finally, the intermediate objectives and injections identified by the PRT and FRT are utilized as inputs into the TT allowing development of specific implementation plans for the proposed solution.

The TP tools have been successfully applied in a variety of settings. Gattiker and Boyd (1999) document the ability of the TP tools to direct continuous improvement efforts to achieve significant improvement in item availability and customer service. Rahman (2002) and Chaudhari and Mukhopadhyay (2003) utilize TP tools to identify critical strategic success factors in supply chain management. However, it is Taylor and Sheffield (2002) analysis of the application to TP tools to medical claims processing that underscores the systematic nature of the tools by identifying employee pay as a constraint to revenue enhancement due to errors in remitting medical claims.

It should be noted that the TP tools and those associated with lean, quality management, and process reengineering are mutually supportive, not mutually exclusive. For instance, Deming's Plan-Do-Check-Act cycle can utilize a CRT to identify the core problem. The ‘‘Do’’ stage, identification of an appropriate solution, can be achieved by developing the EC and FRT. Furthermore, implementation of the solution is structured and project planning is facilitated by means of the PRT and TT. Similarly, process mapping and the CRT/FRT can be used to augment each other. The process map can be used to gain a clear understanding of both the current and proposed system while the CRT/FRT can be used to identify sources of problems, including those originating from policies, and identify potential impediments to change. Integrating tools from a variety of sources in this manner may result in a better understanding of the problem, improve the development of solutions, and enhance the probability of successful implementation.

In a logical extension of the Thinking Process application tools, several authors have begun to experiment with the use of the tools for analyzing and formulating strategy. Klein and Debruine (1995) present an application of TP tools to identify deficiencies in industry-level and corporate-level strategies. Boyd et al. (2001) move beyond strategy analysis to provide insight into strategy formulation. To analyze the external competitive environment and identify what to change, the authors employ the CRT. The EC and FRT tools are utilized to identify what strategy to adopt. Finally, the PRT and TT are used to develop plans for strategy implementation. This approach is mirrored by Dettmer (2003a,b) and Smith (2000); with Dettmer's seven-step ‘‘Constraint Management Model’’ approach the most sophisticated application of the TP to the strategy formulation process.

A new application tool has emerged in response to TOC's expansion into the area of strategy formulation. Goldratt et al. (2002) introduces the strategy and tactics tree (STT), a graphic depiction of the hierarchal structure between goals, objectives, intermediate objectives, and tactics. The STT consists of a chain of interrelated strategic objectives and tactics sequenced as a series of prerequisites, each required to achieve the overall goal. In doing so, the STT appears to combine elements of the PRT and TT; however, it does so while using entities that are unique to this application. As a new tool in an emerging field, the maturation of the STT will be interesting to observe.

6. Era 5: critical chain

At the 1990 International Jonah Conference, a method for scheduling and controlling projects based on TOC logic, critical chain project management (CCPM), was introduced. Unfortunately, the critical chain concept remained unstudied until Goldratt's *Critical Chain* appeared in 1997. Since its reintroduction, a great deal has been written about CCPM (Elton and Roe, 1998; Leach, 1999; Umble and Umble, 2000; Steyn, 2001; Raz, 2003; Cohen et al., 2004); however, the methodology remains unchanged. In that sense, CCPM has not evolved; yet it remains an effective method of project management.

The logic of CCPM is best explained in Newbold's (1998) *Project Management in the Fast Lane*. At its most basic, CCPM is the application of the Five Focusing Steps to project management, employing buffers at critical control points to leverage greater project performance by protecting against and proactively managing task completion time variation. CCPM is similar to critical path project management; however, three major differences exist: the method of assigning activity times, the use of buffers, and the elimination of resource conflicts.

Determination of task activity times has traditionally relied on estimates from those assigned with the task. Since activity times vary depending on the availability of materials, workers, tools, and in some cases the weather; it is natural for the estimator to build a margin of error into the estimate. Therefore, it is not uncommon to have estimates reflecting 90–95% confidence that the activity will be performed within the estimated time. Further, the practice of scheduling to time rather than completion prevents project managers from taking advantage of the buffers built into each individual task. Therefore, should a task exceed its estimate for completion, the entire project will be delayed. Thus, variation in individual task completion time accumulates and on-time delivery is compromised.

CCPM insists that activity time estimates be 50% estimates, yielding considerably shorter task durations. To protect the project due date against overages in completing individual tasks, a project buffer is placed at the end of the project network. Additionally, Pittman (1994) recommends that critical chain activities be ‘‘scheduled to completion,’’ requiring resources along the critical chain to be available to take advantage of early completions; however, this is expensive so non-critical activities remain scheduled to time. To insure that non-critical activities do not impact the start of critical chain tasks, ‘‘feeding’’ buffers are scheduled where the non-critical and critical activities converge.

Based on infinite capacity logic, traditional project management techniques such as critical path (CPM) do not consider resource conflicts. Thus it is likely that CPM schedules contain at least one resource scheduled to perform two different activities simultaneously rendering the project schedule infeasible. CCPM protects against this problem by using a Gantt chart approach to avoid and resolve resource conflicts. The effect of this procedure is to create a dynamic critical path through the project, allowing the critical chain to jump between linear project paths to reflect resource contention. In practice, this means that the critical chain reflects not only the longest aggregate project completion time, but also the completion time considering resource contention.

Results achieved with CCPM are impressive; Leach (2000) describing CCPM successes in the information technology sector states that ‘‘companies such as Texas Instruments, Lucent Technologies, Honeywell and Harris Semiconductor complete projects in one half or less the time of previous or concurrent similar projects, or as compared to industry standards.’’ By contrast, the Standish Group reports that among Information Systems projects traditionally managed, only 16.2% are completed on time and to budget. Of the rest, over half are abandoned entirely while the others average only 42% of the originally specified functionality despite costing 189% of the original estimate. Despite documented successes, CCPM has drawn criticism for not creating optimal project schedules. Herroelen et al. (2002) illustrate that the critical chain approach does not guarantee the shortest network. However, their paper misses two critical points. First, they fail to consider that a dense network may not be shortest once buffers to protect project completion are added. Second, they fail to consider that the real power of critical chain is managing the project so the planned time is actually achieved.

In situations where critical and non-critical paths are of similar length, addition of feeding and project buffers will have a greater impact on estimated project completion than in situations where the project paths have relatively greater discrepancy in length. This reflects the problem of estimating completion times in dense networks. However, even this example misses the main point; traditional networks are managed to bring individual tasks in on time. In contrast, CCPM is designed to produce schedules that bring projects in on time and provides a method to proactively manage them to mitigate harm caused by variation in task completion time. In the management or control portion of critical chain networks, the penetration of buffers is monitored. If the proportion of buffer penetration exceeds the proportion of the project completed, project crashing is carried out until the proportion of the project completed once again exceeds the proportion of buffer consumed.

A second criticism offered by Herroelen and Leus (2001) relates to the means by which buffers are sized. In the manufacturing environment buffer management is employed to modify buffer size, reflecting the degree of variability in the operations of the plant. However, projects are generally one-time occurrences producing unique outputs, decreasing the ability of management to modify buffer size during completion of the project. The general method for establishing buffer size in CCPM is to set them equal to 50% of the project completion time. Herroelen and Leus state that this may seriously overestimate the required buffer protection inflating the project completion time. While this argument is logical, it neglects the impact of the use of 50%-completions activity time estimates. This method for estimating completion times yields project networks half the size of those made with 95% estimates. Therefore, even after adding buffers, the completion time of CCPM is generally 25% less than what would be estimated for the same project planned with CPM or PERT. Additionally, projects scheduled and managed according to CCPM are more likely to be completed on time than those managed with either CPM or PERT.

7. Identified deficiencies in the literature

Before discussing what appears to be the emergence of a sixth era in the evolution of the Theory of Constraints, we believe that it is important to review deficiencies with the techniques developed during the previous five eras. This is done in the vein of constructive criticism, so that problems impeding greater acceptance of TOC can be more clearly examined and addressed. If TOC is to gain the elusive mainstream acceptance its proponents and creator believe it deserves, TOC researchers and practitioners will need to address these deficiencies in addition to pointing to real world successes.

A common criticism that has impeded TOC's widespread dissemination in the academic literature is that TOC techniques produce results that are feasible but not always optimal. The view of many TOC proponents is that while optimization results in elegant schedules, the schedules are infeasible due to assumptions that are invalidated by exposure to real world variability. This has created a void regarding scheduling and sequencing of production, design of unbalanced lines, establishing batch size, establishing initial buffer size, and determination of the optimal product mix. While heuristics are available; they are sometimes ill-defined or lack rigorous testing. Additionally, while it is conventional wisdom that OR, JIT, or MRP techniques can be employed, it is unclear if there is a preferred method for use in TOC systems. These areas require research to define TOC techniques and to compare, contrast, and seek possible collaboration between TOC and various other techniques.

A second area to be addressed is to define characteristics of TOC systems. While there has been recent activity in this area (Gupta et al., 2002), failure to address it previously has resulted in a number of studies that confuse the question of TOC's performance. For example, ill-defined procedures for applying TOC have lead researchers to conclude that when comparing JIT to TOC, TOC produces: (1) less output with more inventory (Lea and Min, 2003), (2) more output with less inventory (Fogarty et al., 1991; Cook, 1994), and (3) more output with less inventory until inventory is sufficient to cover variability and then JIT produces more output for the same inventory (Chakravorty and Atwater, 1996). In the absence of clear evidence, the reader is left questioning whether a true difference between performance of JIT and TOC systems exists in practice.

A deficiency in the Throughput Accounting literature is a degree of ambiguity with regard to definitions. Foster et al. (1998) suggest one reason inaccurate definitions are allowed to propagate, Goldratt's use of traditional accounting terminology with new definitions and intermingling these definitions with their traditional counterparts in his writing. A second cause is the use of the PQ to examine deficiencies in traditional accounting methods. Ironically, many PQ articles create ambiguity with regard to the definition of throughput, which most treat as price minus raw material cost. However, this definition is incomplete; Goldratt (1990) is clear on the subject, similar to the total cost concept and direct costing, throughput calculations must not only consider material costs, but must also include the costs associated with subcontracting, sales commissions, customs duties, and transportation. This problem is significant enough that it was addressed directly by Balderstone and Keef (1999), though inaccurate definitions continue to be used in the academic literature and textbooks.

A second deficiency of TA is the perceived lack of a means to determine product cost and establish price. TOC proponents suffer from an aversion to allocation of overhead expense confusing the process of fully costing a product; in fact, Dr. Goldratt has gone so far as to disavow the notion of product cost altogether. However, this leads to valuation problems and prohibits the use "cost plus" as a means to establish price. Noreen et al. (1995) and Corbett (1998) report that TOC does have established procedures for determining the lowest acceptable price based on the type of constraint found in the supply chain. This heuristic establishes a price floor, below which the company should not produce or sell the product; however, the upper bound on price is established by what the market is willing and able to pay. This procedure is congruent with Goldratt's frequent statements that price should be set by the market, not dictated by cost. Caspari and Caspari (2004) have suggested a procedure to "correctly" establish market prices; however, this model is so new that it has not been fully evaluated and its impact on the continuing development of TOC is impossible to determine.

A third major deficiency of TA is its perceived short term nature with relation to product costing, capital investment decision making, and strategic planning. As Smith (2000) points out, "Goldratt's simplistic approach of tying compensation to cash flow – advocated by the throughput, inventory, and operating expense measures – has been correctly criticized for not recognizing the need for long-term vision in executive decision-making" (p. 131). Variable costing and the reduction of inventory found in TOC reduces the incentive to create apparent profits but does not address how to align management decision-making with long term corporate goals. This has lead to confusion regarding how to forge a link between the TOC performance measurement system and long-term planning. Conventional wisdom states that TOC measures when used for making short term decisions are compatible with Activity-based Costing for longer planning horizons (Kee and Schmidt, 2000; Kee, 2001). However, there are clear philosophical differences between Throughput Accounting and ABC (Cooper and Kaplan, 1988; Kaplan et al., 1990). This philosophical divide may be too great for TOC advocates to embrace ABC; it is clear that Goldratt does not find the use of ABC an acceptable solution (Noreen et al., 1995). Smith (2000) suggests an alternative that may provide at least a partial solution, economic value management; however, at present, there does not appear to be a clear direction for resolving this deficiency.

Review of the Thinking Processes leads to consideration of two common problems. First, those within the academy state that, due to their reliance on subjective interpretation of perceived reality and the qualitative nature of the subject matter, the tools are inherently unreliable. Failure by TOC researchers to establish TP tool validity and reliability is an area within the body of knowledge that must be resolved. Boyd et al. (2001) addresses this concern by discussing a means for validating the application of TP tools for strategy formulation. No doubt this type of research will become increasingly important for continued growth and development of the TP tools.

A second criticism of the Thinking Process tools is that they are not user friendly. While there is little doubt that they will continue to undergo improvement, there are indications that Dr. Goldratt may be moving away from their widespread application in order to improve accessibility of TOC solutions. Recognizing the difficulty in educating top management in the use of the Thinking Processes tools, Dr. Goldratt has introduced Viable Vision for use by consultants. The premise of Viable Vision is to increase a firm's performance to such an extent that profits exceed current sales within a 4 years period. This is achieved through implementation of generic TOC Thinking Process solutions customized for a particular company. Viable Vision is originally slated to be limited to eight manufacturing and distribution environments which have thoroughly understood and tested Thinking Process solutions. It is believed that boiler-plating generic solutions and providing a regimented implementation process under the Viable Vision banner will improve not only accessibility to TOC solutions but assure successful implementation.

8. Era 6: the future of TOC

The Theory of Constraints celebrated its Silver Anniversary in 2004. During those 25 years, it has evolved from a production scheduling software package to an integrated management philosophy spanning numerous operations management subdisciplines. It now appears that TOC may have entered a sixth era, an era in which TOC is poised to transition from niche to mainstream. We believe that there are clear signals from both the academic and practitioner communities indicating emergence of this new era. It appears that first generation subject matter experts from both communities have initiated activities to insure continuation of the philosophy. This is significant because we believe the emerging era will see a significant number of retirements in the ranks of first generation subject matter experts; indeed, these retirements appear to have begun. This will necessitate the emergence of new academicians and practitioners to lead the field forward.

It is clear that the TOC community is preparing for this transfer of leadership. As evidence of this assertion, the newly created Theory of Constraints International Certification Organization (TOCICO) appears to be in the initial phases of collecting and archiving the cumulative body of knowledge. TOCICO is also creating a dictionary and a series of standardized tests to certify mastery of various TOC techniques. These actions will insure a common vocabulary and rigorous uniform standards of skill mastery on an international level; actions that will serve to clarify current ambiguities in both practice and concept definitions. Additionally, TOCICO's efforts appear well timed to take advantage of TOC's resurgence in popularity.

Evidence of emergence of new era in the TOC academic community is given by a clear change in tenor of TOC literature and an increased level of acceptance of TOC research. Newly published articles are moving away from anecdotal evidence of potential benefits, case studies, and comparisons of proposed methods to the more detail oriented work required to complete the body of knowledge. We have also noted the emergence of studies reporting mutually supportive aspects between TOC and various other operations management methodologies. Additionally, through discussions with colleagues we understand that exploratory studies to determine the characteristic features of TOC systems and the organizational, cultural, and structural characteristics most conducive to TOC implementation have recently been undertaken or are planned. This research stream is particularly important, because while it is generally agreed that TOC is a pragmatic and holistic approach to continuous improvement, covering disparate functionalities under a common theoretical foundation, and consists of an integrated suite of tools focused on those things that limit greater performance relative to the goal; a better understanding of specific techniques and environmental variables is necessary to insure successful implementation and wider acceptance.

Beyond the noted content changes, there has been an explosion in number of manuscripts published. Of the 400+ books, dissertations, academic articles, magazine articles, conference proceedings, reports, etc. reviewed for this study, more than 50% had been written since 1998. Additionally, the quality of the journals publishing peer reviewed TOC research has improved considerably over this same time span. This increased level of acceptance seems to stem from the potential benefits available from the implementation of TOC practices. A comprehensive review of publicly disclosed benefits resulting from implementation of TOC reports not only improvement in operational and/or financial performance but improvement in the range of an order of magnitude better (Mabin and Balderstone, 2000). These findings include:

- a 70% mean reduction in order-to-delivery lead time from a sample of 32 observations with more than 75% reporting a reduction greater than 50%;
- a 65% mean reduction in manufacturing cycle time based on 14 observations;
- a 49% mean reduction in inventory from a sample of 32 observations;
- a 63% mean increase in throughput/revenue, excluding one outlier of +600% at Lucent Technologies, from a sample of 22, 5 of which increased revenue +100%;
- a 44% mean improvement in due date performance from a sample of 13.

While these potential benefits may drive acceptance in the near term, to sustain recent gains, the TOC community must address the problem of obtaining top management support. Due to a perception that TOC is an operations strategy and the length of training required to achieve mastery of the subject, many top level managers have delegated implementation to mid-level managers. This level of support and commitment is insufficient to sustain success because TOC requires a shift in organizational philosophy, measurement, and practice. Therefore, as with nearly all process improvement strategies, top management support appears essential. Failure to address this and the other deficiencies we have identified in the current literature may frustrate further development. While we expect many of the deficiencies will be addressed by the current wave of research and by the actions currently being driven by the practitioner community, this study should serve as a call for research into these areas. Our belief is that addressing these deficiencies will create opportunities for greater acceptance of TOC practices and principles in the mainstream.

References

Aggarwal, S.C., 1985. MRP, JIT, OPT, FMS? Harvard Business Review 63 (5), 8–16.

Alber, K.L., Walker, W.T., 1998. Supply Chain Management: Principles and Techniques for the Practitioner. APICS, Falls Church, p. 80.

Atwater, J.B., Chakravorty, S.S., 1995. Using the theory of constraints to guide the implementation of quality improvement projects in manufacturing operations. International Journal of Production Research 33 (6), 1737–1761.

Balderstone, S., Keef, S.P., 1999. Exploding an urban myth. Management accounting. Magazine for Chartered Management Accountants 77 (9), 26.

Blackstone Jr., J.H., Cox III, J.F., 2004. APICS Dictionary. APICS, Alexandria, VA.

Bond, T.C., 1993. An investigation into the use of OPT production scheduling. Production Planning and Control 4 (4), 399.

Boyd, L.H., Cox III, J.F., 2002. Optimal decision making using cost accounting information. International Journal of Production Research 40 (8), 1879–1898.

Boyd, L., Gupta, M., Sussman, L., 2001. A new approach to strategy formulation: opening the black box. Journal of Education for Business 76 (6), 338–344.

Button, S.D., 1999. Genesis of a communication current reality tree—the three cloud process. In: Constraints Management Symposium Proceedings, APICS, Alexandria, VA.

Button, S.D., 2000. The three-cloud process and communication trees. In: Constraints Management Technical Conference Proceedings, APICS, Alexandria, VA.

Bylinski, G., 1983. An efficiency guru with a brown box. Fortune 108, 120–132.

Caspari, J.A., Caspari, P., 2004. In: Hoboken, N.J. (Ed.), Management Dynamics: Merging Constraints Accounting to Drive Improvement. John Wiley & Sons.

Chakravorty, S.S., Atwater, J.B., 1994. How theory of constraints can be used to direct preventive maintenance. Industrial Management 36 (6), 10–14.

Chakravorty, S.S., Sessum, J.I., 1995. Developing effective strategies to prioritize set-up reduction in a multi-machine production system. International Journal of Operations and Production Management 15 (10), 103–112.

Chakravorty, S.S., Atwater, J.B., 1996. A comparative study of line design approaches for serial production systems. International Journal of Operations and Production Management 16 (6), 91.

Chaudhari, C.V., Mukhopadhyay, S.K., 2003. Application of theory of constraints in an integrated poultry industry. International Journal of Production Research 41 (4), 799.

Cohen, I., Mandelbaum, A., Shtub, A., 2004. Multi-project scheduling and control: a process-based comparative study of the critical chain methodology and some alternatives. Project Management Journal 35 (2), 39–50.

Cook, D.P., 1994. A simulation comparison of traditional, JIT, and TOC manufacturing systems in a flow shop with bottlenecks. Production and Inventory Management Journal 35 (1), 73–78.

Cooper, R., Kaplan, R.S., 1988. Measure costs right: make the right decision. Harvard Business Review 66 (5), 96.

Corbett, T., 1998. Throughput Accounting. North River Press, Great Barrington, MA.

Cox III, J.F., Howe, W.G., Boyd, L.H., 1997. Transfer pricing effects on locally measured organizations. Industrial Management 39 (2), 20–29.

Cox III, J.F., Blackstone Jr., J.H., Schleier Jr., J.G., 2003. Managing Operations: A Focus on Excellence. North River Press, Great Barrington, MA.

Cox III, J.F., Mabin, V.J., Davies, J., 2005. A case of personal productivity: illustrating methodological developments in TOC. Journal of Human Systems Management.

Cox III, J.F., Draman, R.H., Boyd, L.H., Spencer, M.S., 1998. A cause-and-effect approach to analyzing performance measures. Part 2. Internal Plant Operations. Production and Inventory Management Journal 39 (4), 25–33.

Dettmer, H.W., 2003a. Strategic navigation: the constraint management model. In: APICS International Conference, Las Vegas, Nevada.

Dettmer, H.W., 2003b. Strategic Navigation: A Systems Approach to Business Strategy. ASQ Quality Press, Milwaukee, WI.

Elton, J., Roe, J., 1998. Bringing discipline to project management. Harvard Business Review 76 (2), 153.

Fogarty, D.W., Blackstone, J.H., Hoffman, T.R., 1991. Production and Inventory Management. South-Western Publishing Co., Cincinnati, OH.

Foster, B.P., Sullivan, M.C., Ward, T.J., 1998. An empirical test of the view of inventory as a liability in explaining financial distress. Journal of Applied Business Research 14 (2), 83.

Fox, R.E., 1987. Theory of constraints. In: NAA Conference Proceedings.

Fry, T.D., 1992. Manufacturing performance and cost accounting. Production and Inventory Management Journal 33, 30–35.

Fry, T.D., Cox III, J.F., 1989. Manufacturing performance: local versus global measures. Production and Inventory Management 30 (2), 52–57.

Fry, T.D., Cox III, J.F., Blackstone Jr., J.H., 1992. An analysis and discussion of the optimized production technology software and its use. Production and Operations Management 1 (2), 229–242.

Gardiner, S.C., 1993. Measures of product attractiveness and the theory of constraints. International Journal of Retail and Distribution Management 21 (7), 37–40.

Gardiner, S.C., Blackstone Jr., J.H., 1991. The 'Theory of Constraints' and the make-or-buy decision. International Journal of Purchasing and Materials Management 27 (3), 38.

Gardiner, S.C., Blackstone Jr., J.H., Gardiner, L.R., 1993. Drum-buffer-rope and buffer management: impact on production management study and practices. International Journal of Operations and Production Management 13 (6), 68–78.

Gattiker, T.F., Boyd, L.H., 1999. A cause-and-effect approach to analyzing continuous improvement at an electronics manufacturing facility. Production and Inventory Management Journal 40 (2), 26–31.

Goldratt, E.M., 1980. Optimized production timetables: a revolutionary program for industry. In: APICS 23rd Annual International Conference, APICS, Falls Church.

Goldratt, E.M., 1981. The unbalanced plant. In: APICS 24th Annual International Conference Proceedings, APICS, Falls Church, VA.

Goldratt, E.M., 1983. Cost accounting: the number one enemy of productivity. In: International Conference of the American Production and Inventory Control Society.

Goldratt, E.M., 1988a. The fundamental measurements. The Theory of Constraints Journal 1 (3), 1–21.

Goldratt, E.M., 1988b. Computerized shop floor scheduling. International Journal of Production Research 26 (3), 443–455.

Goldratt, E.M., 1990. The Haystack Syndrome: Sifting Information Out of the Data Ocean. North River Press, Great Barrington, MA.

Goldratt, E.M., 1994. It's Not Luck. North River Press, Great Barrington, MA.

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

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

Goldratt, E.M., Fox, R.E., 1986. The Race. North River Press, Croton-on-Hudson, NY.

Goldratt, E.M., Goldratt, R., Abramov, E., 2002. Strategy and Tactics.

Gupta, M., Ko, H.-J., Min, H., 2002. TOC-based performance measures and five focusing steps in a job-shop manufacturing environment. International Journal of Production Research 40 (4), 907.

Herroelen, W., Leus, R., 2001. On the merits and pitfalls of critical chain scheduling. Journal of Operations Management 19 (5), 559–577.

Herroelen, W., Leus, R., Demeulemeester, E., 2002. Critical chain project scheduling: do not oversimplify. Project Management Journal 33 (4), 48.

Holt, J.R., 1999. Candid Comparison of Operational Management Approaches. Washington State University-Vancouver, Vancouver, pp. 1–11.

Hopp, W.J., Spearman, M.L., 2000. Factory Physics: Foundations of Manufacturing Management. McGraw-Hill Higher Education, New York.

IMA, 1999. Practices and Techniques: Theory of Constraints Management Systems Fundamentals. Montvale, NJ, Institute of Management Accountants and Arthur Andersen LLP, p. 67.

IW/MPI, 2003. Census of Manufacturers: Executive Summary. IndustryWeek/Manufacturing Performance Institute, Cleveland, OH, p. 20.

Jacobs, R.F., 1983. The OPT Scheduling System: A Review of a Production Scheduling System. Production and Inventory Management 24 (4), 47.

Johnson, A., 1986. MRP? MRP II? OPT? CIM? FMS? JIT? Is any system letter-perfect?. Management Review 75 (9), 22–27.

Johnson, H.T., Kaplan, R.S., 1987. Relevance Lost: The Rise and Fall of Management Accounting. Harvard Business School Press, Boston, MA.

Kaplan, R.S., 1983. Measuring manufacturing performance: a new challenge for managerial accounting research. The Accounting Review 58 (4), 686–705.

Kaplan, R.S., 1984. Yesterday's accounting undermines production. Harvard Business Review 62 (4), 95–101.

Kaplan, R.S., 1986. Accounting lag: the obsolescence of cost accounting systems. California Management Review 28 (2), 174–199.

Kaplan, R.S., Shank, J.K., Horngren, C.T., Boer, G.B., Ferrara, W.L., Robinson, M.A., 1990. Contribution margin analysis: no longer relevant/strategic cost management: the new paradigm. Journal of Management Accounting Research 2, 1.

Kee, R.C., 2001. Evaluating the economics of short- and long-run production-related decisions. Journal of Managerial Issues 13 (2), 139.

Kee, R., Schmidt, C., 2000. A Comparative analysis of utilizing activity-based costing and the theory of constraints for making product mix decisions. International Journal of Production Economics 63 (1), 1.

Klein, D.J., Debruine, M., 1995. A Thinking process for establishing management policies. Review of Business 16 (3), 37.

Koziol, D.S., 1988. How the constraint theory improved a job-shop operation. Management Accounting 69 (11), 44–49.

Lambrecht, M.R., Decaluwe, L., 1988. JIT and constraint theory: the issue of bottleneck management. Production and Inventory Management Journal 29 (3), 61–65.

Lambrecht, M.R., Segaert, A., 1990. Buffer stock allocation in serial and assembly type of production lines. International Journal of Operations and Production Management 10 (2), 47–61.

Lea, B.-R., Min, H., 2003. Selection of management accounting systems in just-in-time and theory of constraints-based manufacturing. International Journal of Production Research 41 (13), 2879.

Leach, L.P., 1999. Critical chain project management improves project performance. Project Management Journal 30 (2), 39.

Leach, L.P., 2000. Critical Chain Project Management. Artech House, Boston.

Lockamy III, A., Cox III, J.F., 1994. Reengineering Performance Measurement: How to Align Systems to Improve Processes, Products and Profits. Irwin Professional Publishing/APICS, Burr Ridge, IL.

Lockamy III, A., Spencer, M.S., 1998. Performance Measurement in a Theory of Constraints Environment. International Journal of Production Research 36 (8), 2045–2060.

Low, J.T., 1993. Theory of constraints: a model for applying the theory to purchasing. APICS: The Performance Advantage 3, 1.

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

Newbold, R.C., 1998. Project Management in the Fast Lane: Applying the Theory of Constraints. St. Lucie Press, Boca Raton, FL.

Noreen, E.W., Smith, D., Mackey, J.T., 1995. IMA Foundation for Applied Research and Price Waterhouse. The Theory of Constraints and its Implications for Management Accounting. North River Press, Great Barrington, MA.

Perez, J.L., 1997. TOC for world class global supply chain management. Computers and Industrial Engineering 33 (1/2), 289–293.

Pittman, P.H., 1994. Project Management: A More Effective Methodology for the Planning and Control of Projects Management. University of Georgia, Athens, GA, xiii, 237.

Raban, S., Nagel, R.N., 1991. Constraint-based control of flexible flow lines. International Journal of Production Research 29 (10), 1941–1951.

Rahman, S., 2002. The theory of constraints' thinking process approach to developing strategies in supply chains. International Journal of Physical Distribution and Logistics Management 32 (10), 809.

Ramsay, M.L., Brown, S., Tabibzadeh, K., 1990. Push, pull and squeeze shopfloor control with computer simulation. Industrial Engineering 22 (2), 39–45.

Raz, T., 2003. A critical look at critical chain project management. Project Management Journal 34 (4), 24–32.

Reid, R.A., Cormier, J.R., 2003. Applying the TOC TP: a case study in the service sector. Managing Service Quality 13 (5), 349.

Scheinkopf, L.J., 1999. Thinking for a Change: putting the TOC thinking processes to use. St. Lucie Press, Boca Raton, FL.

Schragenheim, E., Ronen, B., 1990. Drum-buffer-rope shopfloor control. Production and Inventory Management Journal 31 (3), 18–22.

Schragenheim, E., Ronen, B., 1991. Buffer management: a diagnostic tool for production control. Production and Inventory Management Journal 32 (2), 74–79.

Schragenheim, E., Dettmer, H.W., 2000. Manufacturing at Warp Speed: Optimizing Supply Chain Financial Performance. St. Lucie Press, APICS, Boca Raton, FL.

Simatupang, T.M., Wright, A.C., Sridharan, R., 2004. Applying the theory of constraints to supply chain collaboration. Supply Chain Management: An International Journal 9 (1), 57–70.

Smith, D., 2000. The Measurement Nightmare: How the Theory of Constraints can Resolve Conflicting Strategies, Policies and Measures. St. Lucie Press, Boca Raton, FL.

Spencer, M.S., 1994. Economic theory, cost accounting and the theory of constraints: an examination of relationships and problems. International Journal of Production Research 32 (2), 299–308.

Spencer, M.S., Cox III, J.F., 1995. Optimum production technology (OPT) and the theory of constraints (TOC): analysis and genealogy. International Journal of Production Research 33, 1495–1504.

Srikanth, M.L., Robertson, S.A., 1995. Measurements for Effective Decision Making. The Spectrum Publishing Company, Guilford, CT.

Steyn, H., 2001. An investigation into the fundamentals of critical chain project scheduling. International Journal of Project Management 19 (6), 363.

Taylor III, L.J., Sheffield, D., 2002. Goldratt's thinking process applied to medical claims processing. Hospital Topics 80 (4), 13.

Umble, M., Srikanth, M.L., 1995. Synchronous Manufacturing: Principles for World Class Excellence. Spectrum Publishing Company, Wallingford, CT.

Umble, M., Umble, E., 2000. Manage your projects for success: an application of the theory of constraints. Production and Inventory Management Journal 41 (2), 27.

Watson, K.J., Polito, T., 2003. Comparison of DRP and TOC financial performance within a multi-product, multi-echelon physical distribution environment. International Journal of Production Research 41 (4), 741–765.

Weston Jr., F.C., 1991. Functional Goals are Often in Conflict with Each Other. Industrial Engineering 23 (11), 25–29.