Theory of constraints

A review of the philosophy and its applications

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Introduction

Today's businesses are competing increasingly on time and quality. Companies cannot survive if they fail to obtain competitive advantages by producing high quality products and services in shorter throughput time and quicker inventory turnover. Since the early 1970s, three important approaches have evolved for companies to achieve competitive advantages, each challenging old assumptions and ways of doing things. These are materials requirements planning (MRPI and MRPII), just-in-time (JIT), and theory of constraints (TOC).

Developed by Eli Goldratt in the mid-1980s (Goldratt, 1988) TOC evolved from the OPT (Optimized Production Timetables) system (Goldratt, 1980) and was later known under the commercial name of Optimized Production Technology (OPT®). As part of a marketing tool for the OPT system, Goldratt illustrated the concepts of OPT in the form of a novel (Goldratt and Cox, 1984) in which the theory is gradually unravelled through the context of an everyday production situation. The concepts identified in this book (*The Goal*) were more fully developed as results from actual implementations became known. A second book, titled *The Race* (Goldratt and Fox, 1986), was written to overcome difficulties encountered in the implementations. It presented a logistical system for the material flow called the drum-buffer-rope (DBR) and, gradually, the focus of the concept has moved from the production floor to encompass all aspects of business. By 1987, the overall concept became known as the theory of constraints (TOC) which Goldratt viewed as "an overall theory for running an organisation" (Goldratt, 1988, p. 453). This refinement recognised that the main constraint in most organizations may not be physical but managerial-policy related. To address the policy constraints and effectively implement the process of on-going improvement, Goldratt (1990b, 1994) develop a generic approach called the "thinking process" (TP). This is the current paradigm of TOC. Experts believe that it is the TP of TOC which will ultimately have the most lasting impact on business. The aim of this paper is to present a comprehensive list of publications on TOC using a classification framework based on its

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philosophy and applications in business disciplines, and to identify future research areas in TOC.

The concept

The concept of the TOC can be summarised as:

- *Every system must have at least one constraint*. If it were not true, then a real system such as a profit making organisation would make unlimited profit. A constraint therefore, "is anything that limits a system from achieving higher performance versus its goal" (Goldratt, 1988, p. 453).
- *The existence of constraints represents opportunities for improvement*. Contrary to conventional thinking, TOC views constraints as positive, not negative. Because constraints determine the performance of a system, a gradual elevation of the system's constraints will improve its performance.

The TOC has two major components. First, a philosophy which underpins the working principle of TOC. It consists of the five focusing steps of on-going improvement, the drum-buffer-rope (DBR) scheduling methodology, and the buffer management information system, and is usually referred to as TOC's "logistics" paradigm. The second component of TOC is a generic approach for investigating, analysing, and solving complex problems called the thinking process (TP). In addition, TOC prescribes new performance measurements which are quite different from the traditional cost-accounting system. We discuss these components in the following sub-sections.

Philosophy

The working principle of TOC provides a focus for a continuous improvement process. The principle consists of five focusing steps (Goldratt, 1990b, p. 5) which are summarised in Figure 1. The steps are:

(1) *Identify the system's constraint(s)*. These may be physical (e.g. materials, machines, people, demand level) or managerial. Generally, organisations have very few physical constraints but many managerial constraints in the form of policies, procedures and rules and methods (Goldratt, 1990b). Recently, Goldratt (1993, 1994) developed a technique called a Current Reality Tree to identify policy constraints. It is important to identify these constraints and also necessary to prioritise them according to their impact on the goal(s) of the organisation.

(2) *Decide how to exploit the system's constraint(s)*. If the constraint is physical, the objective is to make the constraint as effective as possible. A managerial constraint should not be exploited but be eliminated and replaced with a policy which will support increased throughput.

(3) *Subordinate everything else to the above decision*. This means that every other component of the system (nonconstraints) must be adjusted to support the maximum effectiveness of the constraint. Because

constraints dictate a firm's throughput, resource synchronisation with the constraint provides the most effective manner of resource utilisation. Nonconstraint resources contain productive capacity (capacity to support the constraint throughput) and idle capacity (capacity to protect against system disruptions and capacity not currently needed) (Lockamy and Cox, 1994). If nonconstraint resources are used beyond their productive capacity to support the constraint, they do not improve throughput but increase unnecessary inventory.

(4) *Elevate the system's constraint(s)*. If existing constraints are still the most critical in the system, rigorous improvement efforts on these constraints will improve their performance. As the performance of the constraints improve, the potential of nonconstraint resources can be better realised, leading to improvements in overall system performance. Eventually the system will encounter a new constraint.

(5) *If in any of the previous steps a constraint is broken, go back to step 1. Do not let inertia become the next constraint*. The first part of this step makes TOC a continuous process. The second part is a reminder that no policy (or solution) is appropriate (or correct) for all time or in every situation. It is critical for the organisation to recognise that as the business environment changes, business policy has to be refined to take account of those changes. Failure to implement step 5 may lead an organisation to disaster.

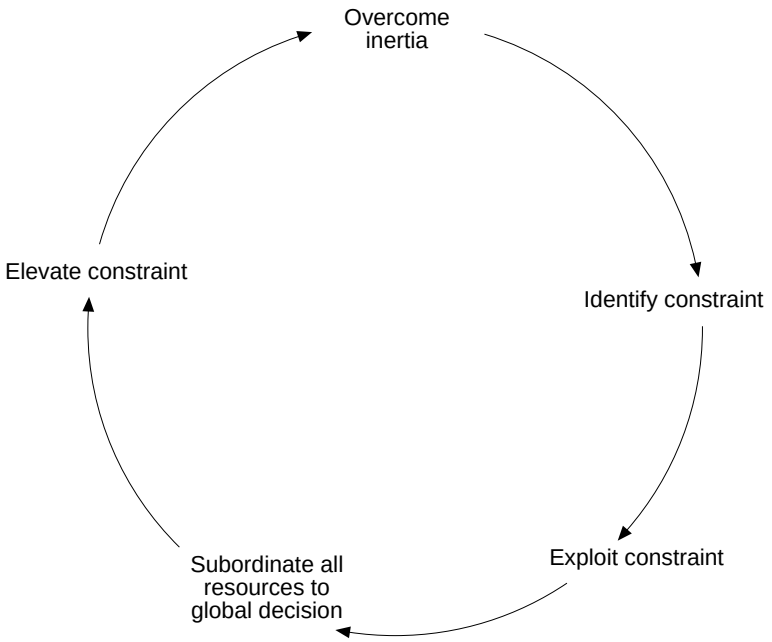

Figure 1.
Process of on-going improvement

Drum-buffer-rope and buffer management

The logistics paradigm of the TOC has evolved from the scheduling software called optimised production technology (OPT) which in turn, is based on the following nine rules (Goldratt and Fox, 1986, p. 179):

(1) Balance flow, not capacity.

(2) The level of utilization of a non-bottleneck is not determined by its own potential but by some other constraint in the system.

(3) Utilisation 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 inventories.

(7) The 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 the constraints simultaneously. Lead times are the result of a schedule and cannot be predetermined.

When OPT became available initially it was presented as a competitor for MRP (I and II) and JIT (Fox, 1982a, 1982b; Aggarwal, 1985; Everdell, 1984; Plenert and Best, 1986). It also attracted considerable criticism, and continues to be criticised because of the claim that it offers an optimal schedule, and because of the fact that the algorithm on which it is based has never been revealed in the literature. It is noteworthy that OPT and its nine rules are no longer part of the current TOC approach.

The implementation of the logistical system of TOC is governed by the drum-buffer-rope (DBR) methodology and managed through the use of time-buffers (T-Bs). The name of the method is based on metaphors developed in *The Goal* (Goldratt and Cox, 1984). The *drum* is the system schedule or the pace at which the constraint works. *Rope* provides communications between critical control points to ensure their synchronisation. *Buffer* is strategically placed inventory to protect the system's output from the variations that occur in the system. The DBR methodology synchronises resources and material utilisation in an organisation. Resources and materials are used only at a level that contributes to the organisation's ability to achieve throughput. Because random disruptions are inevitable in any organisation, DBR methodology provides a mechanism for protecting total throughput of the system by the use of T-Bs. Time-buffers contain inventory and protect constraint schedule from the effects of disruptions at non-constraint resources. The use of T-Bs as an information system to effectively manage and improve throughput is referred to as buffer management. It provides information based on planned and actual performance and is used for monitoring the inventory in front of a protected resource to

compare its actual and planned performance (Schragenheim and Ronen, 1990). Three types of T-B are used in buffer management (Lockamy and Cox, 1991):

(1) *Constraint buffers*: contain parts which are expected to wait a certain amount of time in front of a capacity constraint resource (CCR), thus protecting the constraint's planned schedule. A CCR is a resource that is not a bottleneck at present, but, if not managed properly, it can become a constraint.

(2) *Assembly buffers*: contain parts/subassemblies which are not processed by a CCR, but need to be assembled with CCR parts.

(3) *Shipping buffers*: contain products which are expected to be finished and ready to ship at a certain time before the due date, thus protecting delivery date performance.

Figure 2 shows the locations of these three T-Bs. Notice that an assembly buffer is not required before every assembly operation. It is required only before assembly operation that is fed by both CCR and non-CCR parts. The constraint buffer is located in front of the CCR and the shipping buffer is located at the end of the process. The use of T-Bs in buffer management can help spot the causes of disruptions without disrupting throughput. Moreover, by continually reducing buffer sizes, production cycle time can be reduced which in turn may

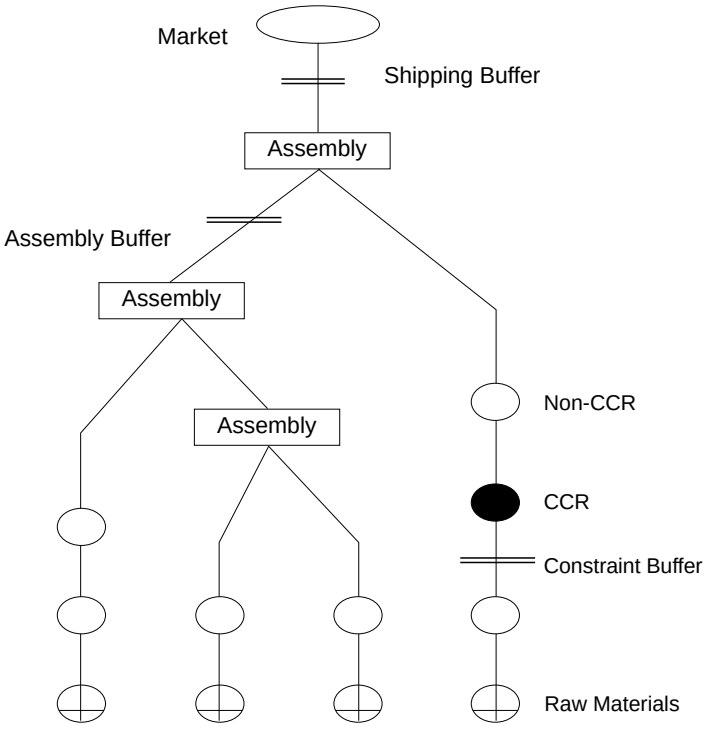

Figure 2.
Locations of buffers

reduce lead time. For a detailed discussion on DBR methodology and buffer management readers are referred to Goldratt and Fox (1986).

Thinking process

The implementation of the five focusing steps to a typical production environment can quickly yield substantial improvements in operations and in profits (Noreen *et al.*, 1995). However, this process of continuous improvement takes the production operations to a point where the constraint shifts from factory floor to market. In such a case, constraint could be market demand (insufficient demand) which is a managerial/policy constraint rather than a physical constraint. Policy constraints are generally difficult to identify and evaluate, and frequently require involvement and cooperation across functional areas.

Recently, Goldratt (1994) developed a generic approach to address policy constraints and create breakthrough solutions for them using common sense, intuitive knowledge and logic. This procedure is referred to as the thinking process (TP). According to Noreen *et al.* (1995, p. 149) "the TP may be the most important intellectual achievement since the invention of calculus".

According to Goldratt, while dealing with constraints managers are required to make three generic decisions. These are:

(1) Decide what to change.

(2) Decide what to change to.

(3) Decide how to cause the change.

The TP prescribes a set of tools, which basically are cause-and-effect diagrams, to get answers to these questions. The questions, associated tools and their purposes are summarised in Table I. The TP process starts with the first decision question, "What to change?", i.e. to identify core problems. The current reality tree is used for this purpose. Once a core problem has been identified, the decision question becomes "What to change to?". Answering the second question requires other tools such as evaporating cloud and future reality tree. Once the "what to change to?" question is decided, then the organisation is left with the question "how to do it?" or "how to change?". The prerequisite tree and transition tree diagrams are used to identify obstacles to implementation and devise detailed plans for overcoming these obstacles. It is not the purpose of this paper to discuss these tools in great detail. For a detailed discussion readers are

Generic questions	Purpose	TP tools
What to change?	Identify core problems	Current reality tree
What to change to?	Develop simple, practical solutions	Evaporative cloud, Future reality tree
How to cause the change?	Implement solutions	Prerequisite tree, Transition tree

Table I.
TP tools and their roles

referred to Goldratt (1994) and Noreen *et al.* (1995). In their recent survey among seven manufacturing companies, Noreen *et al.* (1995) observed that the TP process was used infrequently, despite its great potential. However, experts believe that TP will ultimately have the most lasting impact on business.

New performance measurements

TOC assumes that the goal of an organisation is to make money both now and in the future. To measure an organisation's performance in achieving this goal, two sets of measurements have been prescribed by Goldratt and Fox (1986, p. 31): global (financial) measurements and operational measurement. Since global measurements can be expressed through the operational measurements, operational measurements are defined first.

(1) Throughput (T): the rate at which the system generates money through sales (output which is not sold is not throughput but inventory).

(2) Inventory (I): all the money invested in things the system intends to sell.

(3) Operating expense (OE): all the money the system spends in turning inventory into throughput.

Throughput is represented as sales minus "totally variable" cost. Inventory includes any physical inventories such as raw material, work in process, unsold finished products, and includes tools, building, capital equipment and furnishings. Operating expense includes expenditures such as direct and indirect labour, supplies, outside contractors and interest payments. A detailed explanation of these definitions can be found in Goldratt and Fox (1986).

There are three global measurements:

(1) Net profit (NP): an absolute measurement in dollars expressed as total T minus OE.

(2) Return on investment (ROI): a relative measurement which equals NP divided by the inventory (I).

(3) Cash flow (CF): a "red line" of survival which is an "on-off" type measurement, i.e. when a company has enough cash, it is not so important, but when there is not enough cash, nothing is more important than cash for its survival.

Since the two sets of performance measurements are related, it is possible to assess the impact of each of the operational measurements on the global measurements. When T is increased without adversely effecting I and OE, then all three global measurements are simultaneously improved. The same result is obtained when OE is decreased without harming T and I. However, the impact of I is not so simple. When I is decreased, only ROI and CF are improved but NP remains unchanged. The impact of reduced inventory, however, can be realised indirectly through the reduction of carrying costs which is a component of the OE. The operational measurements can be used to describe other

measurements such as inventory turns (T divided by I) and productivity (T divided by OE).

Management traditionally emphasises reduction of OE first, followed by increasing T and, finally, reducing I. Goldratt suggests that the biggest gains can be realised by first increasing T, then by reducing I. The reduction of OE should be the last priority. The rationale for this order of priority is based on the fact that the reward from decreasing costs (OE costs and I costs) is finite (a theoretical lower limit is zero, a realistic limit is of course considerably higher), but theoretically, increased profit from improved sales is unrestricted.

Clearly, the performance measurements of TOC are very different from traditional cost accounting systems. Maskell (1991, pp. 45-7) identified five problem areas associated with traditional accounting systems in today's business environment: lack of relevance; cost distortion; inflexibility; subjection to the needs of financial accounting; and impediment to progress in world class manufacturing. World class companies are increasingly competing on competitive edges that are nonfinancial in nature: throughput time, inventory turnover, process flexibility, product introduction responsiveness etc. (Schmenner, 1988). As a result, there exists a mismatch between the goal of the company and traditional accounting practices. Among others, Umble and Srikanth (1990) suggest that traditional accounting systems be replaced by one that can adequately evaluate the effect of managerial actions on the productivity and profitability of the entire firm, and recommend use of the performance measurements of TOC.

Literature review

Since the publication of an article by Goldratt in the *APICS 23rd Annual International Conference Proceedings* in 1980 (Goldratt, 1980), many papers have been published on TOC and its related techniques. To explain the underlying philosophy, and to demonstrate the working rules of TOC, Goldratt and his associates have written a number of books. They have also published the *Theory of Constraints Journal*, dedicated solely to the TOC. An extensive literature search has been conducted to identify articles published in refereed and non-refereed journals, as well as papers published in conference proceedings between 1980 and 1995. The TOC based dissertations were not considered as a part of the literature search. Only papers published in refereed journals were considered for further analysis. However, papers published in non-refereed journals and conference proceedings (mostly APICS conference proceedings) have been cited as a separate entity (see Table II). For the list of refereed papers the search was carried out in the following journals:

- *Computers & Industrial Engineering*;
- *Engineering Costs & Production Economics*;
- *European Journal of Operational Research*;
- *Harvard Business Review*;

Table II.
Articles in other journals and conference proceedings

Journal	Year																
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Total
Accountancy																1	1
Advanced Manufacturing Engineer										1							1
Air Force Journal of Logistics													1				1
Baylor Business Review												1					1
Bibbin															1		1
Charted Accountants Journal of NZ																1	1
Corporate Controller													1				1
Fortune				1													1
Human Systems Management															1		1
Iron Age						1											1
Industry Week												8	6				14
Industrial Computer								1									1
Journal of Systems Improvement																1	1
Production Engineering							1										1
Management Review							1										1
Manufacturing Systems																	1
New England Business								1									1
Rydges							1										1
Success															1	1	2
Tutorial Paper (ORS, UK)											1						1
The Performance Adv (APICS)														1			1
Management Accountant's Handbook														1			1
Conference Proceedings	1	2	2	4	2	2		2	1	1							17
Total	1	2	2	5	2	3	3	4	1	2	1	9	8	2	4	4	53

Journal	Year 1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Total
Production and Inventory Management		1			5		1	1	1	5	2	1	4	2	23
International Journal of Operations & Production Management						1		2				1			4
Industrial Management									1				2		3
Industrial Engineering			1					2	1	1					5
Inventories and Production	2	3													3
Computer and Industrial Engineering									1				2		5
Omega													1		1
Interfaces							1								1
International Journal of Production Research							1	1		1	1	1	1		6
Harvard Business Review				1											1
Management Accounting (UK)							2	2			1	1		1	7
Management Accounting (USA)				1		1	1		1			2	1	5	12
Quality Progress														1	1
Production and Operations Management											1			1	2
Engineering Costs and Production Economics				1				1	2						4
International Journal of Production Economics										2	1		1		4
European Journal of Operational Research								1	1			1			3
International Journal of Purchasing and Materials Management										1					1
Total	2	4	1	3	5	2	6	10	8	11	6	6	12	10	86

Table III. Classification of articles: by year, in selected journals

- *Industrial Engineering*;
- *Industrial Management*;
- *Interfaces*;
- *International Journal of Operations & Production Management*;
- *International Journal of Purchasing and Materials Management*;
- *International Journal of Production Economics*;
- *International Journal of Production Research*;
- *Inventories and Production*;
- *Journal of Operations Management*;
- *Journal of Operational Research Society*;
- *Management Accounting (UK)*;
- *Management Accounting (USA)*;
- *Omega*;
- *Operations Research*;
- *Production and Inventory Management*;
- *Production & Operations Management*;
- *Quality Progress*.

No article on TOC was published in the *Journal of Operations Management*, *Operations Research*, or the *Journal of Operational Research Society* over the period between 1980 and 1995. Papers relating to TOC/OPT began appearing in conference proceedings in 1980. The first journal article was published in 1982 (Fox, 1982a).

Articles, published in the refereed journals and the books on TOC were reviewed separately. The author believes that this article contains the first comprehensive review of referred academic literature relating to the philosophy and application of TOC. Its main objectives are to:

(1) divide the contributions into three broad categories – TOC philosophy, TOC applications, and TOC books;

(2) classify each broad category into subcategories;

(3) identify future research directions.

A total of 139 articles was identified of which 86 were published in refereed journals and the others in other non-refereed journals and conference proceedings. Articles published in the *Theory of Constraints Journal* were not considered for review. The vast majority of articles appeared in *Production and Inventory Management* and in two *Management Accounting* journals (UK and USA) (see Table III for publication in each journal by year). Table IV categorises articles according to theme. Those in each category were then subcategorised on the basis of type of study:

- Conceptual: explaining the basic principles of TOC.
- Enhancement: extending TOC principles to different theoretical problem settings.
- Comparison: comparing TOC with other systems such as MRP, JIT, CIM.
- Application: application of TOC in business areas.

The articles in each category were classified according to type of study: conceptual, enhancement, comparison, and area of application – production, purchasing, accounting, administration, education, quality – and are identified in the "References" section as [C], [E], [CN], [P], [PU], [AC], [A], [ED], [Q] respectively. The framework used for the survey is shown in Figure 3.

Classified into two categories were 12 books on TOC: those written to explain the concepts of TOC and those based on the concepts of TOC to analyse other areas of business.

Table IV indicates that the major focus of published articles has been to convey the concepts and principles of TOC. Some compare TOC with other production techniques such as JIT and MRP. It was observed that most of the articles which focused on the "enhancement" subcategory also discussed the "conceptual" subcategory of TOC. Therefore, both these subcategories were discussed under the same heading. Each category is discussed in the following subsections.

Literature on the concept and enhancement of TOC concept

A vast majority of articles focus on the concepts and principle of TOC. Jacobs (1983, 1984) and Zmiran (1994) provide insight into the production planning and scheduling concepts of OPT. Lundrigan (1986), Marcus (1986), and Cook (1994) highlight the advantages of OPT in reducing inventories, operating expense and increasing throughput. Schragenheim and Ronen (1990, 1991) provide a detailed description of the working principle of DBR logistic system and use of T-Bs for uninterrupted production scheduling.

Immediately after the introduction of the OPT software, much criticism was directed at the proprietary nature of the scheduling algorithms within the software. Several papers contained a brief description of the software (Jacobs, 1984; Lundrigan, 1986; Vollman, 1986), and a detailed description is given by Fry *et al*. (1992) which also included the batch sizing procedure and user interfaces. Although OPT software is at the heart of scheduling procedure, Jacobs (1984) argued that in many situations production planning and scheduling concepts can be implemented without the software. Through the use of computer simulation, Weeda (1990) and Huisman *et al*. (1990) explored the relation between batch mode, utilization of capacities and throughput. Several articles enhanced the TOC principles to address various theoretical problem settings such as master production scheduling, V-A-T analysis, setup time management (Lockamy and Cox, 1991; Patterson, 1993; Spencer and James, 1995). In a recent article, Dettmer (1995a) compared the system approach taken by TQM and TOC. He argued that TQM views the system in terms of discrete

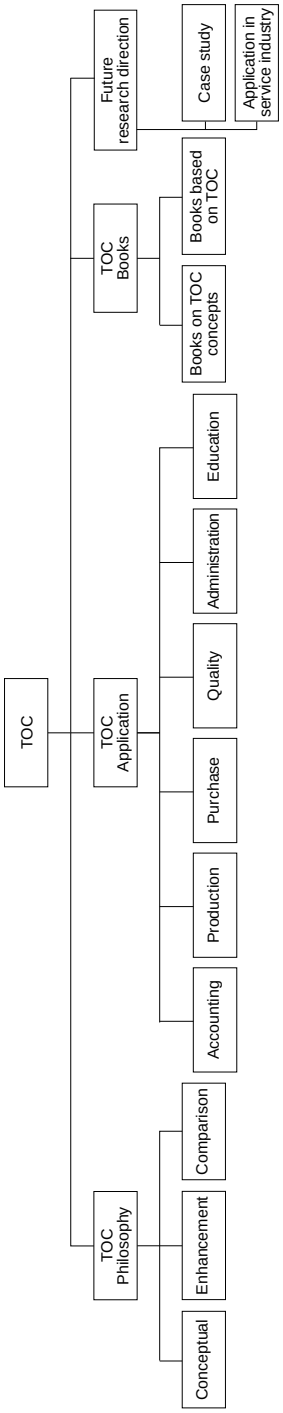

Figure 3.
Framework for the survey

Table IV. Classification of articles: by year, according to the categories

Year/category	Conceptual	Philosophy Enhancement	Comparison	Production	Application Purchase	Accounting	Administration	Education	Quality
1982	1		1						
1983	2	1	1						
1984	1								
1985	1		2						
1986	2	2	1						
1987	1			1					
1988	2	1		1		2			
1989	2	2	2	1		2	1		
1990		5	1	1		1			
1991	1	4	2	1	1	1			
1992		1	4			1			
1993	2	2	2					1	
1994	1	2	3	3		1			1
1995	3	1		5		1			
Total	19	22	19	13	1	9	1	1	1

processes and then optimises the quality in each process, whereas TOC improves performance by concentrating on the weakest link in the total system.

TOC/JIT/MRP/LP comparison

Several articles compared TOC with other production methods such as MRP and JIT. This theme was the general focus at the early stages of the OPT (Fox, 1982a; Everdell, 1984; Aggarwal, 1985). Swann (1986) advocated the use of MRP for net requirements and OPT for realistic shop schedules. Vollmann (1986) considered OPT as an enhancement to MRP II.

Several studies argued that TOC (OPT), JIT and MRP are mutually exclusive inventory control systems (Grunwald *et al.*, 1989). Gelders and Van Wassenhore (1985) expressed similar views and concluded that OPT would come first to plan the bottleneck facilities in the medium time horizon. MRP should be used to generate time-phased requirements while JIT should be used to maximize throughput. However, Plenert and Best (1986) concluded that both OPT and JIT are more productive than MRP, and the TOC system is more complete than the JIT system. Several studies compared the performances of TOC, JIT and MRP using computer simulations (Ramsay, 1990; Neely and Byrne, 1992). A simulation study by Cook (1994) indicated that TOC outperformed JIT on a number of critical performance measures, including total output and standard deviation of flow time. From these studies, it is difficult to conclude with confidence that one system is better than the other. However, the general consensus derived from the comparisons is that an organisation needs a combination of these production control methods to take advantage of each system's strength (Ptak, 1991; Neely and Byrne, 1992).

The TOC has many of the same underpinnings as linear programming (LP), e.g. the notion of shadow price. The TOC principle that an hour gained at a bottleneck is an hour gained for the total system is similar to the notion of shadow price in LP. The shadow price in LP illustrates that an improvement in the objective function is only possible if an additional unit of binding resources was made available. Several studies compared TOC with LP. Lee and Plenert (1993) demonstrated with a numeric example that the scheduling procedure of TOC is inefficient compared with the LP procedure when multiple constrained resources exist. However, Posnack (1994) and Maday (1994) argued that Lee and Plenert's (1993) conclusion is misleading because of the improper use of constraint management. Luebbe and Finch (1992) stated that both TOC and LP can determine the optimal mix and are able to determine the impact of changes in processing time, or machines used or products produced. But TOC adds more operational concepts for dealing with constraining situations. Constraints are explicitly identified and they are buffered with inventory for uninterrupted production process. The goal is always to break a constraint and improve the performance of the system, and therefore continuous improvement is an integral part of the TOC philosophy.

Applications in business areas

While there has been a significant increase in the number of articles on TOC in recent years, there also has been a lack of research on its application. Several

papers have reported on the use of TOC in companies and the benefits obtained from its application (Aggarwal, 1985; Gardiner *et al.*, 1994). Fry *et al.* (1992) conducted a survey of users of OPT software and found that the automotive industry is the main user and that more companies oriented towards make-to-order production have tried the software than have those oriented towards make-to-stock. However, very few papers are based on actual applications. Most research has tackled production problems in the manufacturing environment. Studies by Reimer (1991), Wahlers and Cox (1994) and Darlington (1995) demonstrated the use of TOC to reduce inventory, reduce WIP inventory, reduce lead time, and improve delivery performance. Guide and Ghishelli (1995) reported a unique application of DBR and buffer management at a military rework depot engine works.

Few articles reported the application of TOC in other management areas such as purchasing, quality management, information management (Gardiner and Blackstone, 1991; Chakravorty and Atwater, 1994; Coman and Ronen, 1994). Feather and Cross (1989) observed a reduction in paperwork backlog and an improvement in workers' productivity and morale when the TOC technique was applied to simplify administrative work. Several articles reported the application of TOC concepts in the area of management accounting. A new accounting technique called throughput accounting (TA) has been evolved based on the concepts of TOC (Waldron and Galloway, 1988a; 1988b; 1989a; 1989b). Blake and Hellberg (1991), and Holmen (1995) compared the ABC (activity-based costing) and TA, and concluded that for long-run decision making, ABC is more appropriate whereas for short-run decision making TA should be used.

Book reviews

Books published on TOC may be classified into two categories: TOC books, and books based on TOC philosophy.

TOC books. TOC books explain the basic concepts and principles of TOC and develop the techniques and operational procedures to implement these concepts. These are *The Goal* (Goldratt and Cox, 1984), *The Race* (Goldratt and Fox, 1986), *The Haystack Syndrome* (Goldratt, 1990a), *Theory of Constraints* (Goldratt, 1990b), and *It's Not Luck* (1994).

More than one million copies of *The Goal* have been sold since it was first published in 1984. Though not a textbook or a how-to guide, it addresses manufacturing management, is written in a fast-paced thriller style and delivers the message in a Socratic way. In the introduction Goldratt states that "*The Goal* is about new global principles of manufacturing" (Goldratt and Cox, 1984). More than just a book on manufacturing, it presents a thinking process which provides the context for a new continuous improvement approach in all spheres of business.

In his second book, *The Race*, Goldratt fully developed the logistical system called drum-buffer-rope (DBR), based on metaphors developed in *The Goal*. In addition, Goldratt prescribed a new performance measurements framework which indicates whether or not companies are moving towards their goal. The performance measurements have been further discussed in *The Haystack*

Syndrome which also examines differences between data and information, and explains the logic of the need for information. The five focusing steps of on-going improvement and fundamentals of the TP process were addressed in his next book, *The Theory of Constraints*. In his latest novel, *It's Not Luck*, Goldratt used the TP process to address policy constraints. Techniques such as current reality tree, evaporative Ccloud, future reality tree, prerequisite tree, and transition tree were applied to identify core problems and to offer solutions.

Books based on TOC philosophy. Books based on the philosophy of TOC analyse production systems and business performance using the TOC guideline and compare it with other systems and measures. These are *Synchronous Manufacturing* (Umble and Srikanth, 1990), *Reengineering Performance Measurement* (Lockamy and Cox, 1994), *The Next Phase of Total Quality Management* (Stein, 1994), *The Theory of Constraints and Its Implications for Management Accounting* (Noreen *et al*., 1995), *Goldratt's Theory of Constraints: A Systems Approach to Continuous Improvement* (Dettmer, 1995b), *Measurements of Effective Decision Making* (Srikanth, and Robertson, 1995). In addition, the *Theory of Constraints Journal* is solely dedicated to TOC.

Stein's book (1994) expanded the body of knowledge within the TOC and introduced it as TQM II. Its principles are similar to those of OPT although it encompasses other quality management concepts and techniques such as SPC (statistical process control), QFD (quality function deployment) and DOE (design of experiment). The book by Lockamy and Cox, *Reengineering Performance Measurement*, provided a framework linking three broad functional areas of business (finance, resource, and customer) in order to synchronise efforts and to achieve goals. TOC performance measurements were used within the framework to measure the performance of organisations. In *Synchronous Manufacturing*, Umble and Srikanth used a more traditional term (synchronous manufacturing, which had been used by Goldratt in *The Race*) to represent manufacturing principles of TOC and presented the basic performance measurements developed by Goldratt that underpin the TOC concepts. Srikanth and Cavallaro (1990) in *Regaining Competitiveness* provided a detailed analysis of the case study presented in *The Goal*. Noreen *et al*.'s book (1995) gives a third party view and critique of both the strengths and weaknesses of TOC and its TP process based on their survey among several manufacturing companies.

Conclusions and future research directions

This paper presents a comprehensive review of academic literature on the TOC, including papers published in referred, and non-referred journals and conference proceedings, and books. These are classified on the basis of the TOC philosophy and its application in business disciplines. The review shows that the vast majority of the papers have concentrated on the concept and enhancement of TOC concept. Several articles compare TOC with other production methods such as MRP and JIT. In the application category a number of articles report the application of TOC concepts in the area of production and

management accounting. The articles published in these two subcategories are evenly distributed. However, this review shows that until now only one application of TOC has taken place in each of the other business areas. Although, several papers have referred to the application of TOC in actual business settings, very few cases so far have been reported (Noreen *et al.*, 1995). Future research could be directed towards analysing the case studies of organisations to identify what worked, and did not work and why. Also missing are papers on TOC implementation in the service sector. Only two articles were published in the context of service organisations (Feather and Cross, 1989, Eden and Ronen, 1990). Further investigation of applications of the TOC philosophy in the service sector is required.

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