A Review of Goldratt's Theory of Constraints (TOC) – lessons from the international literature

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Abstract

The two authors are finalising the first comprehensive bibliography on the Theory of Constraints (TOC)[23] which is to be published by North River Press, the publishers of several works on TOC, most notably Eli Goldratt's seminal works [11-17], such as *The Goal, It's Not Luck,* and *Critical Chain.* Based on our extensive search of the literature, this talk will draw on examples of applications of TOC, and summarise important findings on the theory and practice of TOC. Although initially a manufacturing method, TOC has now developed into a theory about management: a powerful systemic problem structuring and problem solving methodology which can be used to develop solutions with both intuitive power and analytical rigour. TOC is increasingly being applied to situations outside the manufacturing context, including distribution, marketing, project management, accounting - in fact, any situation involving change to a system.

1 Introduction

The main motivation for the research reported in this paper was the realisation that TOC is growing very rapidly, and we simply did not know what was "out there"; ie what had already been tackled. Hence our mission two years ago was to conduct a literature search to identify recent works (mostly post 1990). This search has culminated in an annotated bibliography, which is to be published shortly by North River Press [23]. Alongside this literature research grew a Masters thesis, pulling all this material together, both the theory and the practice. [2]

This paper will first briefly outline the background to TOC, and then report on the practice-related material from the survey of published applications and the findings. Readers wishing to gain the benefit of a fuller treatment of this material for a review of the entire TOC field are referred to [2]; while those wishing to obtain a copy of the bibliography are referred to [23].

In its brief 20-year history, TOC has developed rapidly in terms of both methodology (see for example [6], [8]) and area of applications (see for example, [19], 27]). In the late 1970's, the founder of the Theory of Constraints (TOC), Eliyahu Goldratt, Israeli physicist turned business guru, developed a revolutionary method for production scheduling [10] which was in stark contrast to accepted methods available at the time, such as MRP. Central to the TOC philosophy was that any organisation (or system) has a constraint (or small number of constraints) which dominate the entire system. The secret to success lies with managing these constraints, and the system as it interacts with these constraints, to get the best out of the whole system. The Drum-Buffer-Rope scheduling

system, together with the general principles espoused in The Goal, were elements of TOC that became part of successful manufacturing management.

Even so, some companies failed in their attempts to adopt OPT, the software package based on Goldratt's method [10]. Such failure was usually diagnosed as an inability or unwillingness by the organisation to discard old traditions, and embrace the new philosophy and the new measures that were concomitant with successful adoption. The most common measures that need to be reviewed are accounting measures, as TOC promotes the use of global system-wide measures, rather than local measures. The motivation for this is that if a system as a whole is to achieve its goal, it is best for the system's individual parts to work as a team in "sync" rather than at their own individual speeds.

Given that the major constraint to improvement was the resistance to changing these measures, it is not surprising therefore that this is the direction that TOC followed, to tackle this biggest constraint to adoption – behaviours. Thus the TOC Thinking Processes were born: a suite of tools that allows people to learn and use the thinking processes that enable them to develop their own solutions to complex problems. This suite of tools enables analysis of a situation, using the rigour of cause and effect thinking following strict logic rules, combined with the intuition and knowledge of the persons owning, or intimately involved with, the problem. The TP's enable more complex problems ("messes") to be tackled, and have much in common with other soft systems approaches such as SSM and SODA/cognitive mapping.

In our opinion, these thinking processes now offer much to OR/MS practitioners (as well as the more traditional users from the Operations Management field).

2 The Survey

The literature search has uncovered over 310 items on TOC, including 32 books. The majority of these were developing/discussing the methodology from a theoretical viewpoint. Many claims were made regarding the benefits of TOC. These included increased throughputs, reduced inventories and lead-times, which in turn would lead to higher sales, and improved profits, quality, and customer satisfaction.

However we felt it would also be useful to collect together and analyse the actual reported data on the benefits of TOC, to verify or disprove these claims. The literature search identified over one hundred case studies or vignettes that contained information on the results of applications of TOC. Not all cases or vignettes provided quantitative data on the results of applying TOC. In total, we were able to collect quantitative data on the application of TOC to seventy-seven different companies. The types of organisations covered by these cases varied from giant multi-national corporations and industry leaders like Boeing and GM, to military organisations like the US Air Force, to small town bakeries.

The vast majority of TOC applications were in the manufacturing sector. Within this sector, there are significant clusters of applications in the aerospace, apparel, automotive, electronics, furniture, semi-conductor, steel and heavy engineering industries. Most of these focused on the manufacturing operations of each organisation. However, there were several instances of application to administrative functions.

Analysis of the frequency of article and book publications per year shows a considerable growth of publications in recent years. This is partially due to the formation of the Constraints Management Special Interest Group within the influential APICS. This year, we have seen a dramatic increase in the number of books published on TOC, with

nine new books hitting the shelves, including [6], [21], [26]. This takes the total number of books on TOC to 32, since the release of *The Goal* [15] in 1984.

TOC is a complex methodology requiring skill and cooperation to implement. This may be why there have been few "complete" applications of the methodology reported in the literature. Most applications involve components of the overall philosophy, predominantly the operations management technique, DBR, and the constraint oriented continuous improvement technique, the Five Focusing Steps. This is significant as many of the results of applications, summarised below, are the result of only the partial power of TOC.

The case survey methodology [20] used for data collection has limitations, the main one being the lack of consistency in the reporting conventions. Authors used a range of different frames and methods for reporting results. Thus, there were limitations to the types of data that were usable. However, sample size of 78 applications provided sufficient data for robust conclusions for most variables, the only exception being changes in profitability; the small sample size for this is thought to be due to commercial sensitivity. However, this deficiency is made up by a reasonable sample of organisations reporting changes in revenue resulting from the application. In total, a sample of twenty-five data points were gathered for changes in financial performance. Inherent within the case survey methodology is the potential for bias on the part of the authors themselves, and academic journal editors. However the latter bias may be mitigated in part, as articles relating to TOC were published in some 83 different journals and magazines.

The great majority of applications reported in the literature were conducted in North America. A number of European applications were reported, with only a few cases emerging from the UK and Australasia.

2.1 Data Analysis

This research exercise is believed to be the first published examination of the actual performance of the Theory of Constraints[1]. The table in Appendix 1 gives a selection of the results[2]. We were initially concerned that there were so many apparent gaps in the data, as it could be argued that these omissions indicate that these factors were not improved, or that only a few factors in each case improved, perhaps even to the detriment of other factors. However, on reflection we recognised there are many valid reasons for such omissions.

Firstly, several of the measures used are essentially measuring the same effect: eg Lead-time, Cycle Time and Due Date performance all measure the company's ability to respond speedily to customer orders. Thus one would not expect authors to report all measures. Secondly, many companies do not wish to report factors such as financial results, for competitive reasons. Thirdly, many companies adopt TOC with a particular focus, such as to improve due date performance and may fail to give much attention to effects outside this focus.

Furthermore, it is often difficult to collect hard data: people do not always take measurements before they make changes: they may not envisage how effective this approach will be - often they have tried other methods before, and the results have not been noteworthy, so why should this method be any different? Sometimes the results are simply too hard to calculate: eg to calculate the Inventory figures using Goldratt's definition (see [6], [16] or [27]) is problematic if the company's accounts are prepared using normal cost

[1] To our knowledge, the only other published survey of applications to date is that by Noreen, Smith and Mackey [27], which reported in depth on 25 organisations that were using TOC.

[2] The complete table runs to some 7 pages, so is not included here due to the page limit.

accounting conventions (GAPP), as experience with Expozay showed [22]. Or they may have changed the way they measure Inventory as part of the change to TOC, and hence any reported figures would be misleading. Another reason might be that people would prefer not to know how bad things really are at the start.

Finally, when taken in context of the articles themselves, it is apparent that the authors considered TOC to be a success. For all these reasons, the gaps in the data are not considered to be unreasonable.

The data available was analysed using Exploratory Data Analysis methods.

2.2 Findings of the analysis

The results of the analysis of reported changes in operational and financial performance, resulting from the application of TOC, are summarised below:

Lead-Times: **Mean Reduction 69%**

A mean reduction in lead-time of 69% emerged from the sample of thirty-two observations, all of which reported reductions. Over three quarters of the sample experienced reductions in lead-time greater than 50%

Cycle-Times: **Mean Reduction 66%**

In every case where changes in cycle-time were reported, the reports showed a decrease, or improvement in cycle-time. Fourteen observations made up the sample for change in cycle-times.

Due-Date-Performance: **Mean Improvement 60%**

Improving due-date-performance is synonymous with meeting delivery promises to customers. A mean improvement of 60% emerged from the sample. Twelve observations made up the sample for change in due-date-performance. Several organisations experienced improvements of over 100%.

Inventory Levels: **Mean Reduction 50%**

Reducing inventory is associated with reducing lead-times in a DBR system. A mean inventory reduction of 50% resulted from the sample of 28 observations.

Lead-Time and Inventory Reduction: **Correlation 0.77**

Goldratt and Fox (1986) claim that when DBR is applied to a manufacturing system, the reduction in lead-time is strongly correlated with the reduction of inventory level. This research verifies the claims of Goldratt and Fox, as shown by a 0.77 Spearman's Rank Correlation. This analysis was conducted on a sample of thirteen observations where organisations provided data on changes to both lead-times and inventory levels.

Revenue / Throughput: **Mean Increase 68% (outlier exclusive)**

This variable represents the amount of money coming into the organisation. All reports represented increases in revenue or throughput. The impressive mean increase of 68% excludes one outlier, a 600% increase at Lucent Technologies achieved within one year. Five organisations, from the sample of eighteen, reported increases in revenues in excess of 100%, within one financial year.

Combined Financial Variable: Mean Increase 82%

A sample of twenty-five observations for the combine revenue / throughput / profit variable revealed a mean increase of 82%, excluding the 600% increase at Lucent Technologies.

2.3 Conclusions from this analysis:

- In the survey of over 100 cases, no failures or disappointing results were reported.
- Some substantial improvements in operational variables as well as financial variables were reported. On average, inventories were reduced by 50%, production times (measured by lead-times, cycle times or due date performance) improved by over 60%, and financial measures improved by over 80%. In addition, inventory reductions were accompanied by lead-time reductions - a feat not matched by JIT[3].
- The vast majority of cases reported only partial applications of TOC. We are left to wonder whether improvements would have been even greater had more of the methodology been applied.
- The entire survey revealed over 300 articles and books on TOC, of which only a handful contained negative comments, and none of these related to actual applications of the methodology.
- While there were several papers reporting computer simulations comparing TOC with other scheduling methods, typically MRP and JIT, none showed TOC to be inferior to other methods; most showed a significant advantage on most measures.
- TOC evokes some emotive responses, which is not surprising given that TOC challenges some fundamental notions.
- The technical solution to dramatically improving financial and operational performance, is comparatively simple to identify (especially in hindsight[4])
- The major difficulty is overcoming the behavioural tendency of resistance to change.
- TP applications commonly find that underlying core problems are erroneous or deficient measurements, policies and/or training[5]. Often these are found to be outdated, and no longer consistent with the company's goal.
- Not surprisingly, our enquiries and experience have identified a great number of other applications that have not been published: in many instances the results will never be published, because the focus is on internal change management for competitive advantage. Thus the number of applications reported in this survey is certainly an understatement of the situation.

2.4 Trends Observed

- Many of the newer applications involve full use of the Thinking Processes[6].
- TOC is still perceived by many, unfamiliar with the approach, as an operations management technique instead of a systems management philosophy.
- TOC has been developing over the past twenty years, but a surge in interest has occurred in the last year or so.

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[3] In a survey by Corbett, Harrison and Davis [5] of over 200 Australasian firms applying JIT, inventory reductions were reported, but no corresponding decrease in lead times.

[4] As De Bono says, good solutions are usually obvious in hindsight.

[5] Kendall [19] refers to these as the 3 pillars. Our experience supports this finding.

[6] This is partly due to the TP's being a more recent development, but also to the more diverse areas to which TOC is being applied, including the harder, messier problems involving people's behaviours. Typical applications deal with distribution, marketing, and change management more generally.

- More discussion is now dedicated to overcoming the human behavioural barriers to implementation, rather than the technical components of TOC[7].
- A wider range of main-stream operations management texts (eg [3] and [9]) dedicate whole chapters to TOC.
- TOC, TQM, and BPR all emerged in the early 80s (in the USA). TOC has become increasingly popular while TQM and BPR are now widely regarded as "out of favour" due to their lack of success[8].
- A plethora of multi-methodology applications and academic hybrids have emerged. For example, TQM II is born out of a marriage between TOC & TQM [7], and Harris Semiconductors promote the use of SFM (ie TOC), TPM and IYM [21]. Authors look for synergies from multi-methodology approaches, usually combining TOC with what they already know (eg [4], [24], [25]).
- The military, in the USA and Israel, were early adopters of the logistics and scheduling techniques of TOC, and now use the techniques extensively.
- Project management applications appear to be a new fast-growing area using Goldratt's new method for project management described in [14], especially for the management of IT/ IS / software development (see for example [26]).

3 Conclusions

- Based on this survey of published applications, TOC appears to work very well, even with only partial application of methodology.
- TOC is not a panacea, not a recipe, but is a philosophy that helps lead to success.
- TOC methodology contains many elements that are worthwhile additions to the OR/MS toolbox.

Acknowledgements

The authors would like to thank Jeremy Merrin of North River Press for his enthusiastic support, Dr Eliyahu Goldratt for making it all start, colleagues John Davies and Michelle Baron for discussions and support along the way, and to Victoria University of Wellington Internal Grants Committee for research funding for the bibliographic review.

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[7] This is often stated as being the reason for failure of OR/MS projects: either that, or the problem was incorrectly defined in the first place. The TPs help in problem identication (Current Reality Tree) as well as in implementing the solution through use of Transition Trees, and Prerequisite Trees. These are specifically designed to help overcome the resistance to change.

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Appendix 1: A Sample of the Data Relating Improvements in Operational and Financial Variables

Source	Year	Author(s)	Organisation	Cycle Time	Lead-Time	Due Date	Inventory Size	Operating Expenses	Profitability	Revenue or Throughput
Management Accounting, Vol. 68, No. 11: 18 - 22.	1987	Jayson, Susan	General Electric	97%						
Automotive Industries	1988	Callahan	General Motors (Windsor Plant)	94%			50%			
Logistics Spectrum (Fall)	1992	Simons and Moore	Modine Manufacturing Co		75%		70%			
Springs (Fall)	1996	Debra A. Smith	Renton Coil Springs							48% (in 3 mths)
Apparel Industry (December)	1993	Lila Moore	Tiger Brand Knitting Co.				50%			50%
Best Practice (internal newsletter)	1998	Anonymous	Lucas Variety	24%						
APICS - The Performance Advantage March	1997	Wilson, Ken	Ketema A & E		30 - 60%		40%			
APICS: CM Symposium	1996	Atkinson and Paresa	United Airlines Engine Maintenance Plant	50%						
APICS (Australasia) 4th Conference Proceedings	1991	Keller, Robert and Devlin, Howard	BHP - Coated Products Division		20%		20%			
IIE Solutions, Vol. 30, No. 7, 50-51.	1998	Aldred, Katherine	Toyo Tanso USA Inc.		50%					

Source	Year	Author(s)	Organisation	Cycle Time	Lead-Time	Due Date	Inventory Size	Operating Expenses	Profitability	Revenue or Throughput
APICS CM Symposium: 123	1995	Shoemaker L.J.	Zycon Corp.	80%			50%			100%
APICS CM Symposium: 22-23	1997	Pickels D. & Cole H.	Bal Sel Engineering						100%	
APICS CM Symposium: 10-11	1997	Gallagher, N.A.	ITT, (Night Vision Division)	50%						200%
APICS CM Symposium: 5-8	1997	Pirasteh, R.M. & Camp, G.B.	Dresser Industries		77%					
APICS CM Symposium: 154	1996	Wayman W.	Morton International Automotive		50%	28% to 47%	50%			
APICS CM Symposium: 55 - 56	1998	Gronseth, Steve. & Ray, Joe.	Nystrom Inc. (Cesco Products)						470% (3 yrs) 156% ave.	570% (3 yrs) 190% ave.
APICS CM Symposium: 57 - 61	1998	Wagoner, Michael T.	Boeing Printed Circuit Board Centre							35%
APICS CM Symposium: 79 - 83	1998	Joy, Louis W. III & Smith, Francis	EMC Technology		75%					
APICS CM Symposium	1995	Murphy, Robert and Levinson, William	Harris Semiconductor	50%			40%			28% (T)
Aviation and Space Technology Vol.141, No.22	1994	Anonymous	Wyman-Gordon Co.	77%		69%	68%			