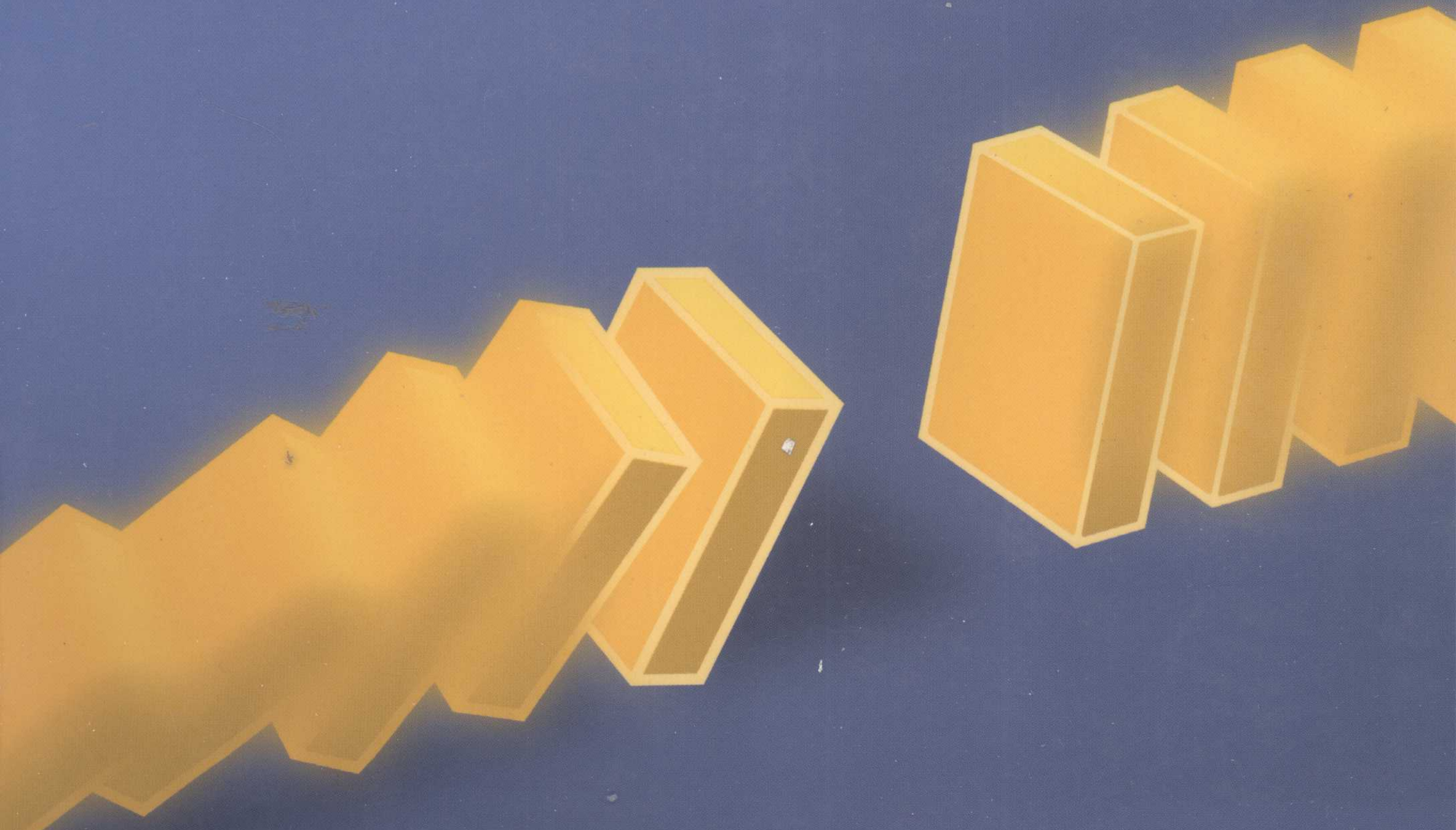
# The Theory of Constraints:
## *Practice and Research*



Edited by: Boaz Ronen

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# The Theory of Constraints: Practice and Research

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# Editorial

# Theory of Constraints: Practice and Research

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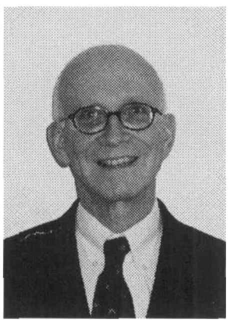

**Boaz Ronen** is a Professor of Technology Management at Tel Aviv University, Faculty of Management, the Leon Recanati Graduate School of Business Administration. He holds a BSc in Electronics Engineering from the Technion, Haifa, Israel, and an MSc and PhD in Business Administration from Tel Aviv University, Faculty of Management. Prior to his academic career he worked for over 10 years in the Israeli Hi-Tech industry. His main areas of interest are focused on increasing shareholders' value. In his work he combines value creation, management of technology, information systems, the strategic and tactical aspects of the Theory of Constraints (TOC), and advanced management philosophies. He has consulted to numerous corporations and government agencies worldwide. During the last 18 years Professor Ronen has been leading a team that successfully implemented TOC and advanced management practices of value creation in dozens of industrial, hi-tech, IT and service organizations. Professor Ronen teaches in the EMBA and MBA programs at Tel Aviv University. He has been commended numerous times and got the Rectors' award for outstanding teaching. He was also a visiting professor at the schools of business of NYU, Columbia University, the Kellogg-Bangkok program at the Sasin Graduate Business School, Stevens Institute of Technology and at the MBA program of SDA-Bocconi (Milan, Italy). Prof. Ronen has published over 100 papers in leading academic and professional journals, and co-authored three books on Value Creation, Focused Management, Managerial Decision Making and Cost Accounting.

The Theory of Constraints (TOC) has spread as a significant managerial philosophy during the last two decades. TOC has been successfully implemented in production, logistics, distribution, project management, research and development and sales and marketing in small and large organizations. Its implementation spans across a multitude of sectors in all industries: the private and public sectors, flow manufacturing as well as job shop operations, start up companies and corporate America, for profit and not-for-profit organizations. If implemented properly, TOC could lead to significant results in a relatively short time.

However, contrary to the vast application of TOC in practice, very little TOC research has been published in refereed academic journals.

Some reasons may be given for the low profile of TOC in research academic journals:

- TOC is a heuristic-oriented philosophy based on Herbert Simon's "Satisficing" approach. Many academic journals prefer process-optimizing, quantitative approaches while the goal of TOC is simplicity.
- TOC processes are cause-effect driven. Academic journals often give preference to field studies with empirical data.
- TOC was originated – like JIT or TQM – by practitioners, rather than by academic researchers. As a result, not enough academics have been exposed to its full contribution.
- TOC is often misperceived as a simplistic toolkit that does not need thorough research.
- TOC is viewed as a cult and thus inaccessible to the academic community.

Many TOC practices have their roots in well established Management Science and Operations Research concepts (for example, the "focusing steps" and the mathematical-programming approach). Some practices have not yet been confirmed by academic research methodologies. It is therefore valuable for both academics and practitioners to apply academic methodolo-

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gies to TOC concepts and confirm or improve its methods.

TOC researchers should also conduct their research using well established academic research rules. Even significant managerial breakthroughs such as TOC should be positioned within the continuity of preceding academic research on managerial practices rather than as institution-free, stand alone concepts. This has happened in the past with JIT/Lean manufacturing and quality improvement. On the other hand, the academic research community should, in some cases, encourage new ideas and methods even if they do not fully follow prevailing academic conventions.

This issue serves as a take-off platform for TOC research, and will hopefully help to close the gap between TOC and the academic world.

I would like to take this opportunity and thank all the people who have contributed their time, effort and expertise to produce this issue. My special thanks go to Shimeon Pass and Alex Coman for their help and to Milan Zeleny for offering us the opportunity to have this issue published.

Boaz Ronen
*Editor*

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# Implementing a pull system in batch/mix process industry through Theory of Constraints: A case-study

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**Abstract.** This paper aims at understanding how the pull production planning approach can be implemented in a batch-mix process business through the Theory of Constraints (TOC). The paper, after a brief review of the main streams of study on TOC, identifies the key academic and managerial issues discussed about the process industries. Among these, a major one concerns production and inventory management for different types of process industries and the need for a transition towards a pull approach. Thus, a case-study is presented, concerning a batch-mix process company, which applied TOC. The paper describes the main features of the process, as well as the key decisions and activities performed in such plant in order to lead the transition to a pull system through the implementation of DBR.

Keywords: Theory of Constraints, process industry, case-study, production planning

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## 1. Introduction

A wide body of literature has been developed so far, based on the analysis and the application of the Theory of Constraints (TOC) in manufacturing and service companies, as well as in several managerial areas, such as project, quality, purchasing and information systems management. As far as production planning is concerned, TOC has been proposed as a new approach suitable to manage operations according to the pull system; in fact, some studies tried to compare TOC with other alternative methods (namely, Just in Time) in order to pinpoint the variables that can affect the choice between them. Although several empirical studies are available on this topic, most of them are based on surveys or on case-studies concerning discrete manufacturing systems, while less attention has been devoted to the application of TOC in process industries. These businesses, due to some technological and managerial features, tend to have a *make to stock* production, which determines a high inventory of finished products, mainly caused by the large production runs. The aim of this paper is to understand how the pull production planning approach can also be implemented in process industry through TOC. In the first part of the paper, after a brief review of the main streams of study on TOC, the key academic and managerial issues of the process industries are discussed. Then a case-study is presented, concerning a specific type of process company, which applied TOC, and some key operational performances are reported in a benchmarking comparison. Finally, the conclusions and managerial implications are proposed.

## 2. Literature review

TOC, proposed by [15] and further developed in later works [13,16], is a management approach based on a continuous improvement process made up of seven steps, the main aim of which is to identify the constraint of an overall process and to overcome it. Within this general framework, a key role is played by the *drum-buffer-rope* (DBR) scheduling technique, operationalized for manufacturing companies through the OPT software (Optimized Production Technology). So far, most of the contributions about TOC have a conceptual nature, since they tend to focus on the analysis of its philosophy and general principles, and seldom encompass a case-study analysis [30]. The empirical evidence shows that the most relevant experiences have been made in the automotive industry and, also, that the application of TOC is more likely to occur in make to order production companies rather than in make to stock ones [11].

Analyzing previous studies about TOC, the main contributions can be divided into four streams:

- TOC as a method for production planning and control in manufacturing companies [22,23,28, 33,36,38];
- TOC implementations in service and not-for profit organizations [24,25,37];
- TOC applications in several management areas, such as purchasing, quality and information systems management [5,12];
- TOC as a method for project scheduling under resource constraints [14,31,38,43].

Among the contributions of the first stream, less attention has been paid to the application of TOC in the process industry.[1] This is a relevant gap, since process businesses can take advantage of the application of the *pull* production planning approach. In fact, the issues covered by the academic literature on process industry can be summed up as follows [7]:

- process industry uniqueness and characteristics [2,9,20,27,29];
- production and inventory management problems and possible solutions [1,5,41];
- production and inventory management taxonomies [7,8,10].

As far as the first point is concerned, it is worthwhile underling several key features that make process industry different from discrete systems: capital intensive production process; low unit value of the product; production quantity measured in terms of physical (e.g., liters, tons, etc.) rather than discrete units; *make to stock* production planning approach; high variability of production time and expected output that depends on different causes, mainly variable quality [21,32] and quantity [4] of raw materials and unstable yield of the process [17].

The second issue is a crucial one. As a matter of fact, the most widely known production planning approaches cannot be successfully implemented in process industries since they don't fit with some of the peculiarities discussed above. According to Taylor and Bolander [41], MRPII can be employed in process industries when custom or low-volume high-differentiated products are manufactured; but, if commodities or high-volume low-differentiated items are produced, the most suitable approaches for process industries are Just in Time and/or Process Flow Scheduling – PFS. However, no empirical evidence has been presented in literature about the application of *pull* techniques in process companies.

The third issue arises from the fact that it is necessary to distinguish among different process industry types because each of them deserves specific production planning logics and techniques. In order to properly choose the production and inventory management approach, the taxonomy developed by Fransoo and Rutten [10] can be useful. According to it, process industries can be classified into two wide categories: batch/mix[2] and process/flow.[3] The former differs from the latter since it generally has: longer lead times; a not well-defined production capacity; a higher complexity of products; shorter changeover times; a larger number of finished products and of production steps, some

[1] Process Industries "... *add value by mixing, separating, forming and/or chemical reactions by either batch or continuous mode*" [42].

[2] Batch/mix is defined as "... a process business which primarily schedules short production runs of products" [6].

[3] Process/flow is defined as "... a manufacturer who produces with minimal interruptions in any one production run or between production runs of products which exhibit process characteristics such as liquids, fibres, powders, gases" [6].

of which are job shops performing a batch production. Due to these differences, it is suggested managing the production process of the batch/mix type according to the *pull* approach, postponing scheduling decisions at the latest possible time. However, no empirical evidence is available about the implementation of this approach in batch-mix processes.

## 3. Methodology

In order to understand in depth what the role played by the TOC approach could be in transforming a push system into a more effective pull one in a batch-mix process company, an empirical study has been conducted. The case study has been identified as the most appropriate methodology for this exploratory research. As a matter of fact, the research questions may be synthesised as follows:

*Why* even in a batch-mix process company a pull system should be pursued?

*When* the TOC approach is the most suitable for the implementation of a pull system?

*How* the production planning process can be redesigned according to TOC principles?

The aim is to understand a phenomenon in depth – the relationship between TOC and production planning in batch-mix process companies – and, in this sense, it has an *explicative* intent. In other words, the goal of this paper is to *explain* the operational meaning of a relationship that has been poorly studied both in theory and in practice. Hence the case study is a sound methodology [46].

The case study has been chosen according to the need to investigate the phenomenon in detail, i.e., a case that allows one to observe and analyse in depth all the relevant variables affecting the decision about the production planning redesign, and to capture the results of this change in terms of better operational performances. The opportunity to exploit different sources of qualitative and quantitative data and information has been considered as well, according to the triangulation principle [46]. To better analyze the main plant performances of the observed company, we explored quantitative data in a twofold direction: on the one hand, according to a longitudinal research approach, we analyzed the plant performances over a three-year period of time, from the year before the launch of the TOC project (1999) to one year after its full implementation (2001); on the other hand we benchmarked the observed plant performances with those of the Italian Best Factory Award (IBFA) process industry cluster. The former step led us to highlight the improvement trends of the specific plant; the latter gave us the opportunity to compare the improvement rates of the observed plant with those of the selected cluster.

The International Best Factory Award is a program run in UK, Germany and Italy, that aims at monitoring plant performances in manufacturing industries and at providing a benchmarking tool for production units that take part in the survey [40,44].

The plant analyzed was selected taking into account two relevant elements:

- being a specialty chemicals manufacturer, it performs a typical batch-mix production process [10]; as far as this point is concerned, it is worthwhile noting that this company has 1800 items at finished products level and a manufacturing lead time for unplanned orders of 21 days; such numbers are much higher than those of the IBFA's process industry cluster, which are respectively 203 and 9 (data are referred to 1999);
- it can be considered an outstanding production unit because it applied most of the main best practices developed in operations management and, moreover, it pioneered the implementation of TOC principles for production process redesign, in Italy.

## 4. Alfachem case-study

Alfachem,[4] an Italian company based in the north of Italy and founded at the beginning of the 20th century, belongs to an international chemical group with a turnover of approximately US$ 310 mln and 1035 employees in 2003. The group manufactures a wide range of chemical products, including carboxymethylcellulose, polyurethane, acrylic polymers, dyestuffs and pigments. The Italian plant, with 350 employees and a turnover of US$ 105 mln in 2003, is a leading European producer of dyestuff for quantity and quality. It produces and synthesizes dyes, pigments and auxiliaries suitable for dyeing all natural, artificial and synthetic fibres, fabrics and leather. Alfachem's production is nearly all sold to fashion-related companies, whose product range is constantly renewed in order to follow the ever-changing preferences of the consumers. In fact, the consumption of dyes in the fashion

[4]For confidentiality agreements, the real name of the company cannot be used; thus, we called the case Alfachem.

industry, within a certain year, varies according to the collections and, from year to year, it follows a pattern that can be hardly foreseen. Even though it operates in an almost consolidated industry as far as process and product innovation is concerned, Alfachem has proved to be an up-to-date company, able to achieve both positive economic performances and high levels of operating efficiency, through the implementation of innovative organizational and managerial solutions.

### *4.1. Best practices and main plant performances*

Over the last few years, to significantly improve plant performances, Alfachem has adopted several managerial practices, such as Total Productive Maintenance [26], Total Quality Management, Continuous Improvement and Statistical Process Control [18,19], Teamworking, Empowerment and Safety Management [45].

The implementation of the above mentioned best practices, along with large investments in up-to-date production equipment, led Alfachem to achieve some relevant results over a five-years period of time, such as 25% increase of productivity and 15% reduction in the production-related employees. Also, in workforce management some relevant results were achieved. First of all, serious attention was devoted to the safety issues, which resulted in a sharp reduction in injury accidents at the plant. Moreover, production-related employees were re-organized into autonomous teams (each including up to 12 workers), responsible for different steps of the production process, according to the principles of TQM and TPM. Furthermore, in order to let the teams fulfill their tasks autonomously, the information system was updated, according to the balanced scorecard model, so as to provide key financial and non-financial performance indicators. These changes determined some important improvements over five years, such as: −20% in absenteeism rate; −30% in scrap rate; −29% in down-times. Moreover, to further enhance the effectiveness of these actions, in the late '90s a performance-related pay-structure was introduced, linked to operational (quality and productivity) and financial (EBIT) indicators.

### *4.2. The implementation of the theory of constraints*

Despite these relevant improvements, some problems still remained: given the high demand unpredictability and the long procurement and production lead-times, the company had adopted a *make to stock* production approach, which resulted, from the customer's perspective, in a 3 days delivery time, and, from the company's standpoint, in a high inventory level. Such a decision, though determining relevant holding costs, was actually necessary, since the delivery time for unplanned orders was up to 21 days in the late '90s, assuming all raw materials available in stock. In the remainder of the paper the main actions undertaken to apply the Theory of Constraints in Alfachem will be presented following the key steps suggested by Goldratt.

#### *4.2.1. Identifying the goal and determining the key measures for improvements*

In Table 1 some *inventory-related indicators* are shown for both the company and the IBFA's process industry cluster. These data highlight a clear weakness of Alfachem in 1999, whose number of stock turns and days of usage, for both raw materials and finished products, were much worse than for the process industry cluster.

In fact, in 1998 the group carried out an internal benchmarking, which led the management to set forth new strategic goals to be pursued in its subsidiaries. One of the main goals was the *reduction of working capital*. In Alfachem this objective could have been achieved only through a dramatic decrease of the inventory. Then, at the beginning of 2000 the *Alfachem*

Table 1
Alfachem's and IBFA's inventory, lead times and demand unpredictability in 1999

| | IBFA* | Alfachem |
|---|---|---|
| Days of usage for raw materials | 55 | 73 |
| Days of usage for finished products ready for shipping | 28 | 60 |
| Number of stock turns | 9.8 | 5.7 |
| Procurement lead time (days) | 31 | 52 |
| Manufacturing lead time for unplanned orders (days) | 9 | 21 |
| Level of unpredictability of customer demand (1: very low; 5: very high) | 3.7 | 5 |

*source: Italian Best Factory Award's process industry database.

*DBR project* was launched, aimed at linking production directly to customer demand, through the application of TOC. According to this project, the reduction of the inventory had to be achieved by cutting the huge stock of finished products due to the inconsistency between the actual demand and the forecasted one.

*4.2.2. Identifying the constraint*

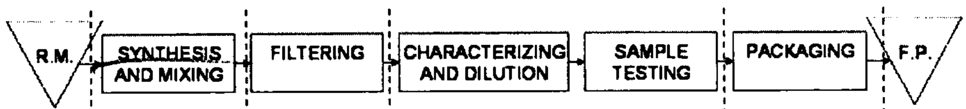
In the Italian plant, the production process encompasses several activities, which can slightly vary according to the type of product to be manufactured (powders vs. liquid dyes). Figure 1 shows a brief description of the main steps for the production of liquid dyes that, being the 75% of the total output of the factory, are the key product line of the plant; for each production step, the key measures and performances (i.e., cycle time, lot size, cost and utilization rate) are reported.

The main steps of the process are as follows:

1. Raw materials picking and transfer to the production lines.
2. Intermediate products manufacturing through chemical synthesis in reactors or through mixers (or blending for powder dyes).
3. Filtering the liquid products; this activity is performed according to standard chemical recipes and is carried out by diluting the product with liquids and oils; downstream this operation, the product is stocked into tanks.
4. Sample-test on the finished product, performed by an internal laboratory, aimed at characterizing the product and at stating whether the specification requirements (mainly the colour) obtained conform to the expected ones; in case of negative assessment, the product undergoes further dilutions due to the variability of the natural raw materials employed. This is a trial and error process that is repeated for an unpredictable number of times, until the product meets the specification standards. In the meanwhile, the production batch under control stays in the tanks and, since their capacity is rather limited, this leads to an interruption of the upstream operation.
5. Packaging finished product in tins (or in bags for powders), which can be different in terms of capacity.
6. Transfer to the finished product warehouse.

The production process is carried out in batches, with an average manufacturing lead time of one week, which can increase up to 21 days for unplanned orders given the high level of saturation. The kind of tin (or bag, for powders) to be used for packaging is chosen according to the orders already in hands and is influenced by the long set-up times: when switching products, tanks must be shut down and cleaned, thus determining both opportunity costs for idle capacity and out-of-pocket costs for waste water treatment.

In Alfachem the department that acts as a bottleneck is the *dilution and sample-testing* one. In fact, since the main raw materials are natural products (such as pigments), given a certain recipe, it is almost impossible to predict the shade of colour that is going to be obtained in each production run; therefore it is necessary to check the output and then to further dilute it in order to fill the gap between the actual nuance and the required one. However, the number of dilution cycles that have to be performed before reaching the desired




| *Stages* | *Synthesis in reactors and mixing* | *Filtering* | *Characterizing, Dilution and Testing* | *Packaging* |
|---|---|---|---|---|
| *Cycle time (hours)* | 4.2 – 5.0 | 1.0 – 1.20 | 1.0 – 1.5 (with *n* possible loops) | 0.8 – 1.0 |
| *Lot size (kg.)* | 2,600-6,200 | | 20,000 – 30,000 | |
| *Cost (%)* | 19 | 23 | 40 | 18 |
| *Utilization (%)* | 80 | 80 | 100 | 70 |

Fig. 1. The production process of liquid dyes.

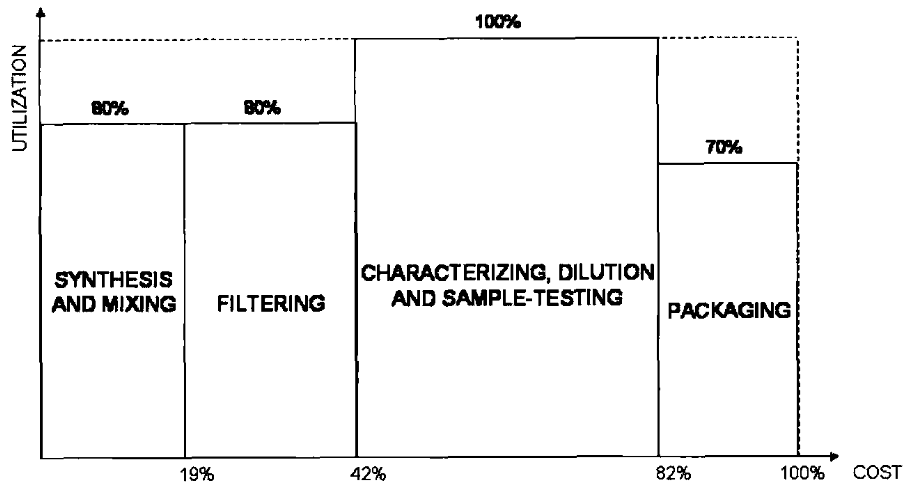



Fig. 2. The cost/utilization method applied to Alfachem.

shade of colour, changes from time to time, thus determining, on the one hand, a very high variability of the lead time of this production step and, on the other, the inability for the management to correctly measure its production capacity; this results in a utilization rate of 100%.[5] This is also due to the fact that the plant works on three shifts per day from Monday to Friday and two shifts per day during the weekend; the internal testing laboratory operates only from Monday to Friday, from 9.00 to 17.00. Therefore, there is a misalignment between the working hours of the plant employees and those of the laboratory. Such problems cannot be easily overcome, since the investment necessary to increase the production capacity of this step is definitely high (see Fig. 2). In fact, to speed up the dilution process, it would be necessary not only to invest in new machinery for the department itself, but also to enlarge the laboratory (where the sample-testing activity is performed), hiring other technicians and buying new equipment.

#### *4.2.3. Utilizing and exploiting the constraint: the DBR system in Alfachem*

Following TOC principles, in 2000 Alfachem implemented the DBR methodology in the production line devoted to liquid dyes, so as to make the whole production system work to the pace of the *drum*. Hence, since 2000 the production planning process in Alfachem concerns only the constraint that, being synchronised with the shipping schedule through an order scheduling optimizer, is in fact pulled by the demand. The operations downstream of the bottleneck just process the dyes released by the dilution department. On the other hand, the upstream departments are pulled by the constraint through a mechanism, the *rope*, which consists of a schedule for releasing raw materials onto the shop floor so that the production plan of the constraint can be respected. Furthermore, as some disruptions in the upstream departments can occur that keep the bottleneck from following its plan, a *buffer* has been put in front of it. This is thought of as a *time buffer*, because its purpose is to absorb possible delays in the upstream operations, which would negatively influence the productivity of the constraint. To determine the time buffer, a statistical analysis was performed, aimed at measuring the variability of the lead time upstream the dilution. According to the main findings of this analysis, the correct buffer had to be equal to the dilution requirement of 8 shifts, i.e., 2.5 days. Thus, the upstream departments are now pulled by the time buffer level and, in fact, they don't process any further product if the buffer doesn't need to be replenished (see Fig. 3). As soon as the level of the buffer goes below 2.5 days of usage, a new production run is launched, whose quantity is on average 1.5 tons. It is worthwhile noting that such batch quantity has sharply decreased over the years thanks to the sound set-up times' reduction that led to a remarkable downsizing of the work in process (lot size moved from 2600–6200 kg – depending on the product – to 1000–2000 kg).

The DBR system has also been applied through the implementation of a latest generation ERP (Enterprise Resource Planning) system, whose scheduling module, through the ATP/CTP (Available To Promise/Capable

[5] In the computation of the utilization rate some events that keep the production line from operating are not considered, namely breakdowns and maintenance.

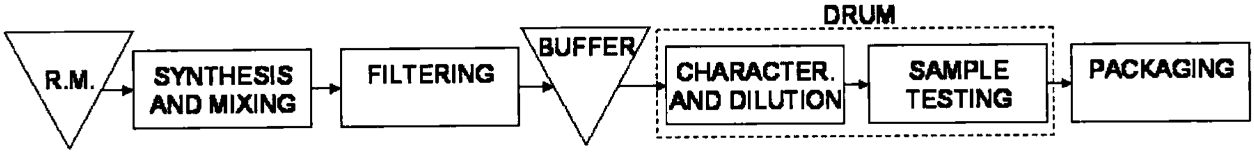



Fig. 3. The drum-buffer-rope system.

To Promise) functionality, supports the company in accepting new orders and defining the most proper sequence according to a given amount of buffer and to the orders already in hand.

Also the procurement underwent some changes. As a matter of fact, in order to streamline the materials flow, it had to be triggered by the demand. Thus new trade agreements were made with the main suppliers to reduce the order quantity usually bought by Alfachem until 2000.

#### *4.2.4. Implementation of the project and key improvements*

The main benefits gained through the *DBR project* are reported in Table 2; even though data are referred to the overall company, it must be highlighted that the lines devoted to liquid dyes (where TOC was implemented), being over 75% of the whole business, can be considered the main source of the performance variations reported. Table 2 is suitable for comparing the improvement rates of the company with those of the IBFA process industry cluster. It also helps in analysing the evolution of some key operational performances of Alfachem over a period of time of 3 years: the data make it possible to assess the performances of the company before (1999) and after (2001) the implementation of the project; data reported in 2000 and 2001 can be employed to highlight the improvements gained through the application of TOC principles.

Even though the *DBR system* was launched in 2000, it brought some remarkable results quite soon. In two years, the DBR led to a sound reduction of the inventory of finished products,[6] whose days of usage dropped from 60 to 28. Furthermore, the new agreements with the main suppliers resulted in a lower inventory of raw materials, that decreased by 14% over the observed period of time, and in a reduction of the procurement lead times, from 52 days to 37.4 days. Jointly, these two actions caused a sound increase in the number of stock turns, which almost doubled between 1999 and 2001. It is also interesting to see that Alfachem's number of stock turns shows an improvement rate (77%) much sharper than the IBFA's process industry cluster one (4%) thus reducing the gap with it. Furthermore, it's worthwhile noting that, even though the company moved from a *make to stock* to a *make to order* production planning approach, the due-date reliability slightly improved, from 97.2% to 98.2%. This interesting effect is due to the fact that, even operating with a push approach, the company often incurred stock-outs because of the unreliability of the demand forecasts; as a consequence, a new production run had to be launched, which was not scheduled, and, due to the high variability of the production process, the actual delivery time was sometimes not consistent with the agreed one. The application of TOC principles was actually feasible thanks to other improvements gained through the implementation of the previously mentioned managerial approaches. In fact, TPM, TQM and SPC supported the company in increasing the machinery availability and in-house quality performances; this led to a sharp improvement in the OEE,[7] which, though being rather low in 1999 compared to the one of the other process companies, grew at a much higher rate (35% vs. 7%). This result was also supported by an improvement in both scrap rate and first time pass rate, the former moving from 1.9% to 1% and the latter from 97.5% to 98.3%. These performances were useful namely at the constraint level, since one of the key rules of TOC involves the exploitation of the bottleneck. Furthermore, the increase of the OEE brought about a reduction in the variability of the manufacturing lead times caused by equipment downtimes, which is another major step in the implementation of the TOC methodology. Of course, these improvements helped in aligning the installed production capacity with the actual demand. A further action to be undertaken in order to increase the production capacity would be a more accurate quality control on the incoming raw materials, which, being natural products, determine a high unpredictability of the output. However, if sales increased, even this action would not be sufficient and it would be necessary to elevate the constraint by enlarging the laboratory. The continuous improvement ap-

[6]The inventory record accuracy was close to 100% over the period of time analysed in this study.

[7]OEE is measured in the most critical production step.

Table 2

Alfachem's performances and comparison with IBFA process industry cluster

| | IBFA* | Alfachem | | | $\Delta_{IBFA}$% | $\Delta_{Alfachem}$% |
|---|---|---|---|---|---|---|
| | | Before Toc imp. | | After Toc imp. | | |
| | 1999 | 1999 | 2000 | 2001 | '99–'01 | '99–'01 |
| Overall Equipment Effectiveness (%) | 82 | 74 | 91 | 99.6 | 7% | 35% |
| Average set-up time for component manufacture (min) | 152 | 240 | 240 | 160 | −28% | −33% |
| Average set-up time for assembly/packaging (min) | 147 | 150 | 100 | 100 | −25% | −33% |
| Manufacturing lead time for unplanned orders (days) | 9 | 21 | 19 | 19 | NA | −10% |
| Procurement lead time (days) | 31 | 52 | 41.6 | 37.4 | −9% | −28% |
| Due-date reliability (%) | 92 | 97.2 | 98.2 | 98.2 | 1% | 1% |
| Scrap rate (%) | 2.2 | 1.9 | 1.1 | 1.0 | −5% | −47% |
| First time pass rate (%) | 97 | 97.5 | 98.1 | 98.3 | 0% | 1% |
| Employees flexibility** (%) | 80 | 44 | 62 | 65.5 | 5% | 49% |
| Days of usage for raw materials | 55 | 73 | 70 | 63 | −56% | −14% |
| Days of usage for finished products ready for shipping | 28 | 60 | 46 | 28 | −36% | −53% |
| Number of stock turns | 9.8 | 5.7 | 6.1 | 10.1 | 4% | 77% |
| Level of unpredictability of customer demand (1: very low; 5: very high) | 3.7 | 5 | 5 | 3 | −12% | −40% |

*source: Italian Best Factory Award's process industry database.

**It is measured as percentage of production-related employees able to carry out more 50% of the production tasks of their area.

proach also resulted in a reduction of 33% in set-up times, for both intermediate manufacturing and packaging. Teamworking, Empowerment and Safety Management also played a key role in the transition towards a *pull* system since the production-related employees were already used to operating in a challenging environment. In fact, along with the improvements already reached on the shop floor, a real cultural change had to be achieved, especially among the production-related employees. As shown in Table 2, even though in 1999 the employee flexibility of the company was far below the average of the process industry cluster, in 2001 it increased by 49%. One of the main consequences in implementing the DBR was that the non-bottleneck production departments were no longer saturated anymore, with a negative impact on their productivity, that raised some scepticism in the production-related employees. Such behavioural problem was due to the performance measurement system used until 2000, which, being based on productivity, made employees convinced that stopping production was inconsistent with the corporate goals. Hence new performance measures were introduced, aimed at monitoring the total lead times, the delays in the constraint's production plan and the economic exploitation of the constraint. As a consequence, employees, whose variable compensation is linked to these new measures, now accept to reduce the pace of the non-bottleneck departments if necessary.

In order to cope with the problem of demand unpredictability, the company's sales force tried to show to the clients that some benefits could have been achieved through a different procurement strategy, based on stronger co-operation. The company was thus able to convince the main clients that, by obtaining data about their requirements of dyes, it was able to grant better service levels and due-date performances. From the company's viewpoint, the availability of this information resulted in a lower demand unpredictability that, as shown in Table 2, dropped from 5 to 3.

## 5. Conclusion, limits and managerial implications

This paper aimed at understanding how TOC can be applied in process businesses, when this approach is the most suitable for the implementation of a pull system, and what benefits it can bring. It is based on a case-study about a batch-mix process company (a producer of dyestuff for fibers, fabrics and leather) that applied the DBR scheduling system. This company, like most process businesses, performed a *make to stock* production process, which, though granting a very quick delivery time to the client, caused a huge inventory of finished products and high holding costs. Thus, the management strove to redesign the production planning according to the pull system and, to reach this goal, it decided to implement TOC. The experience of this enterprise is an interesting one since it shows that TOC can be implemented in any kind of production process; however, in order to lead this change, TOC has to be combined with other managerial practices, which can help in producing some specific improvements necessary for the application of a pull production planning approach through the DBR scheduling system. In fact, on the one hand, TOC was employed, first of all, as a methodology to pinpoint the constraint of the process and then as a reference model for introducing the pull system. On the other hand, TPM, TQM and people management practices enhanced the performances of the process as a whole, leading to remarkable improvements of OEE, in-house quality, machine and employees flexibility, thus contributing to the exploitation of the constraint and to the reduction of the variability of the process. The performances reported by the company have also been compared with some process industry benchmarks and, over the period of time considered in this study, most of them showed higher improvement rates. Furthermore, the application of some collaborative approaches in supply chain management proved to be crucial. In fact, TOC helped the company in sharply cutting the inventory of finished products, thus producing the main benefit that the management was looking for. But, the high variability of the lead time at the constraint level still remained; this problem could have been partially solved by increasing the production capacity of the bottleneck. However the company preferred to overcome it by establishing a collaborative relationship with the main clients, aimed at negotiating slightly longer delivery times with better service levels and due-date performances. This strategy, involving the development of collaborative forecasts with the clients, brought about a reduction in the demand unpredictability and, hence, a better reliability of the production planning process.

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# Significant enhancement of academic achievement through application of the Theory of Constraints (TOC)

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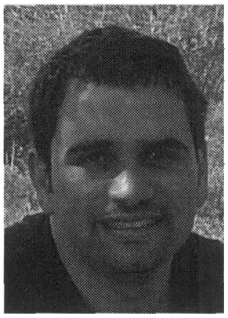
**Abstract.** Changes in the administration of matriculation examinations in Israel (based on the Theory of Constraints), has produced a marked improvement in the high school graduation rate of underprivileged students, without the need for additional manpower or resources and without changing the pedagogical way teachers are asked to teach the relevant knowledge. Because of changes made within the educational system in the early 1990's, the high school diploma has become the prime measure of success also for underprivileged students, within the vocational/technological high school. This article presents a case study of the "Reut" school, where adoption of the Theory of Constraints (TOC) has led to a continuous increase in the number of students eligible for high school diplomas. The article describes the two-phase process of applying the principles of TOC in the administration of matriculation exams. The first phase employs operational flow principles to align the allocation of academic resources according to the weakest link (constraint); the second phase uses TOC project management principles to streamline resource utilization. The improvement achieved at each phase is described together with an analysis of the results. The article ends with conclusions drawn from an analysis of the processes.



**Rami Avraham Goldratt** has been implementing the Theory of Constraints knowledge in various fields such as education, health and across different business environments for 8 years. Rami was one of the early developers of the applications for Education and has earned a reputation in the TOC community as a TOC leader in this field. Rami together with Dr. Eli Goldratt have developed the TOC self learning program called "INSIGHTS" which is considered as a cutting edge know-how of the TOC applications. In the last years Rami was concentrating on developing the application of TOC for the art of selling while working on his PHD thesis in Ethics in the Tel-Aviv University. Rami is a board member of the TOCICO (TOC international certification organization).

**Nava Weiss**, develops training and study materials for process of change in the Israel education system. She has produced workshops for educators using TOC thinking tools. Through the workshops Weiss has develop rich experience in the use of TOC in the realm of education. She has developed educational materials for solving conflicts in daily life using TOC tools. Weiss currently serves on a secondary school management team. She has a Msc. in microbiology from Bar-Ilan University, in Israel.

## 1. Introduction

### *1.1. A Description of Reut High School*

Reut is a religious technical vocation school for girls, located in Petach Tikva, a city in the center of Israel.

The school has 200 students, in the 9th to 12th grades. Most students start the school in the 10th grade. Reut has a dormitory; most of the students reside in the dormitory.

### *1.2. The students' population*

The ethnic origin of the students in the school is diverse. Some of the students were born in Israel, while others are new immigrants from different countries, mainly Ethiopia.