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The theory of constraints as a manufacturing strategy:a case study in a small manufacturing company

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ABSTRACT

The aim of this article is to use with success the Theory of Constraints (TOC) as a strategy in a small manufacturing company. It seeks to prove that this theory does not treat organizations as a collection of independent processes, but rather as an integrated system. Under this theory, the organization is viewed as a synchronized chain, in which the links between each activity form a complete system that is capable of creating synergy for the entire firm. In the business environment, constraints on a firm's production chain have serious consequences, such as poor performance and productivity The Theory of Constraints shows that every system is subject to at least one constraint that keeps it from achieving high levels of performance. Its use repeatedly made it possible to identify the constraints and thus to improve the firm performance and productivity. The results obtained in this research are shown here. The contribution of this research is to provide elements and conditions for small-sized manufacturing firms to use the TOC as a tool to reduce cost and improve performance as a strategy.

Keywords: Theory of Constraints; Strategic differential; Productivity; Manufacture; Small business.

1. INTRODUCTIONS

Theory of Constraints (TOC) can be defined as a procedure for managing factors, production processes, organizational decisions and situations in which there are constraints in the current state. The TOC is a business management tool that links all the manufacturing techniques. It is a scientific methodology that makes it possible to relate the solutions to a firm's critical problems (regardless of its size) to ensure its ongoing improvement process continues unabated.

The TOC is a systematic methodology for company management and improvement. The concepts are very important for manufacturing companies. The contribution of the TOC can be divided into two groups: the thinking process (a set of tools that ease the analysis of and search for systemic solutions to problematic situations) and robust applications based on systemic thinking and operations research methods (production, operations, supply chain, project management, inventory, decision-making, etc.).

Many studies also provide evidence that following the introduction of the TOC, companies achieve an increase in their production quantity and at same time they reduce both inventory and cycle time. The same research validates that the use of TOC techniques produces a better performance when using lean manufacturing, JIT and ERP. The results of these studies show that TOC systems generate higher production levels as they reduce the inventory, production cycle time and cost.

To increase productivity and eliminate possible wasted time and resources with the TOC, a well-designed method can improve system efficiency, by increasing the productivity or decreasing the WIP inventory. In a given manufacturing process, throughput is increased when cycle time is reduced and WIP remains constant. The WIP decreases when the cycle time and throughput are reduced.

The contribution of this research is to provide elements and conditions for small-sized manufactures to use the TOC as a tool within manufacturing to optimize the production process, utilize resources better and reduce manufacturing costs, thereby improving their performance, gaining competitiveness and strengthening the small-sized business.

The Theory of Constraints's essential premise is that all firms have at least one critical constraint that limits their production capacity. A constraint is any element whatsoever that occurs in a system and that keeps the said system from achieving its optimal performance. By using the Theory of Constraints, the management can control the contribution margin and the product's unit production cycle with regard to its critical resources, i.e., its constraints (bottlenecks), thus raising the production capacity.

The TOC can be used on three different levels:

level 1: production management – to solve problems of bottlenecks, production scheduling and reduction of inventories;

level 2: process analysis – application based on the direct costing method instead of traditional cost analysis, making it possible to base the measures taken on the ongoing improvement of processes, system improvements and system constraints, which, in statistical terms, determine the protective capacities, the critical points and their key elements;

level 3: general application of the TOC, aimed at tackling a variety of processing problems within the organization, by applying its logic in order to identify which factors are hindering an organization from achieving its targets and developing a solution to the problem of ongoing improvement.

As a new scientific manufacturing management methodology, the TOC's main objective is to promote ongoing optimization of the expected performance of any organization that has a well-defined **goal**, by focusing the management's actions on those elements that are holding the organization back. It also pursues commitment to total quality and a perfect processing flow in order to achieve continuous productivity gains. Therefore, one can say that productivity is the act of bringing a firm closer to its goal.

Especially in the case of a manufacturing process, all the actions should converge so that the manufacturing plant advances toward its goal: in other words, toward meeting its customers' needs. It should be clear that for an industrial organization to increase its performance and productivity and thus raise its profits, the production flow should be optimized at the "factory floor" level, while stocks should also be reduced drastically, thus lowering the operating expenses.

2. THEORY OF CONSTRAINTS METHODOLOGY

The process of ongoing improvement begins with a clear definition of the organization's **goal**, as well as the establishment of performance measurement parameters that are directly related to this goal. In the case of the private sector, the goal of obtaining profits goes hand in hand with a number of conditions such as quality, price and customer service, among others. These conditions must be satisfied, in the sense of achieving ongoing improvement. Therefore, the organization must use "straightforward and ordinary" language, thus avoiding the frequent communication problems that exist in the business environment. Under a conventional system, evaluating the performance of a manager means checking to see whether or not he achieved the firm's objective. It is necessary to evaluate the result at the end of the period in terms of the following factors: production achieved, net profit, cash flow and return on investment, along with other such items. However, this is only carried out afterwards. The TOC provides a tool for evaluating the result of the process before, during and after it runs (Goldratt, 1987; Goldratt & Cox, 1988; Goldratt & Cox, 1989). Using intermediate indicators allows for synchronized and conscious manufacturing. The indicators suggested are as follows: **value added** (VA) or **throughput**, **inventory** (I) and **operating expenses** (OE).

Value added is defined as the speed with which the system generates financial resources through sales. Inventory represents all the financial resources spent on purchasing production inputs that will be transformed into products. Operating expenses are all the financial resources necessary to turn the materials (I) into throughput (VA). The manufacturing management must keep a market-oriented approach in mind, because profits come from the *value added* produced by sales rather than from the size of the inventory or the plant's performance (Wooldrige & Jennings, 1995). Therefore, in order for a manufacturing process to increase its productivity, it needs to reduce the inventory levels and make the production more flexible by using a more linear flow and avoiding interruptions to the production process (Mu, 2007b). According to Goldratt (2003), the organization will improve its overall performance through conducting manufacturing with regard to its productivity objectives, the performance of which will be measured by net profit, return on investment, productivity and cash flow.

Given the measures, as explained earlier, the firm's personnel can take local decisions, examining the effect of those decisions on the global processing of the production flow and on the reduction in the corporate stock levels with a reduction in the firm's operating expenses, resulting in an optimized decision for the business as a whole (Mu, 2007a). The need for immediate availability and the value of these tools have became important factors in the performance of production areas and, consequently, in the global competitiveness of firms (Shingo, 1987; Plute, 1998; Luh, 2008; Black, 1991; Tooney, 1996; Hwang et al, 2008). The TOC greatly reduces business costs. This becomes clear when the theory's assumptions are compared with the application of the principles of cost accounting (mainly the distribution of costs in order to make decisions at the local level), which leads to inadequate management decisions, both in relation to departments and in the context of the organization's higher levels. Indeed, the TOC virtually eliminates the use of economic order quantities (EOQ) and production lots (Goldratt & Cox, 2002a)

An increase in the flow, as defined, means simultaneously increasing the net profit, return on investment and cash flow. A similar result is observed in terms of the drop in operating expenses. In this case, the production costs are reduced while both the sales flow of products and the stock levels remain constant. A reduction in inventory levels has a direct impact on the return on investment and cash flow. It is necessary for the performance of the organizational processes always to be measured, or at least evaluated, so that one may make continuous improvement (Drucker, 1988). In terms of its concepts, the TOC is the opposite of traditional cost accounting. Figure 1 illustrates a comparison between conventional cost accounting and costs measured by means of throughput accounting.

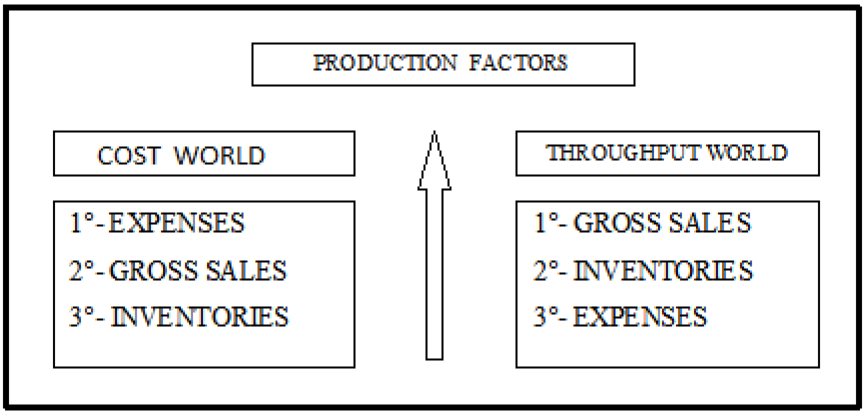

Figure 1. Conventional cost accounting and accounting for costs by means of throughput
Source: Authors' adaptation.

The TOC, like cost accounting, regards firms as a sequence of events. Cost accounting, however, tries to reduce the costs in all of a firm's productive segments. On the other hand, the TOC, which concentrates on the world of *throughput*, maintains its focus, concentrating almost exclusively on the firm's critical resources. The theory is based on the premise that every firm has at least one *critical constraint* that limits its production capacity. By controlling the constraints, the manufacturing management controls the contribution margin and the product's unit production cycle with regard to its critical resources (bottlenecks), altering its capacity. According to Goldratt and Cox (2002), there are two types of critical constraints: physical and political. They can be seen in the simplified diagram of a hydraulic flow that serves as an analogy for what takes place within a firm (see figure 2).

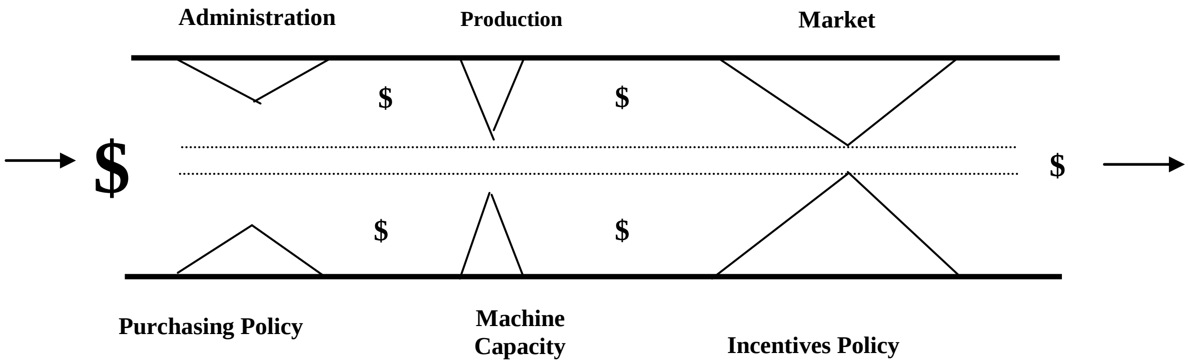

Figure 2. Simplified diagram of the critical constraints
Source. Goldratt and Cox (2002)

In the case of the flow, it does not matter how much water enters via the left-hand side, the amount that can come out on the right-hand side depends solely on the narrowest part of the tube rather than on the numbers of barriers that exist. Therefore, anything that interferes with the hydraulic flow but that does not reduce the largest barrier will be useless.

Likewise, one can say that to generate an increase in production or in profits one must locate the system's critical constraint (*incentives*), in such a way that the constraint changes, becoming just another "barrier" (*machine capacity*). Now it is no longer convenient to continue to intervene in the initial barrier, because this new obstacle becomes the system's key determinant. In this sense, any effort put into a different sequence would be a waste of time and money, since the firm will not achieve its **goal**

2.1. Physical Constraints

As explained above, manufacturing is a chain of events or processes and the sequence of this chain implies the existence and combination of two phenomena: one is called *dependent events* whereas the other is known as *statistical fluctuations*. In order to obtain an ongoing improvement in the case of physical constraints, the TOC establishes a five-step decision process (Goldratt & Cox, 2002b):

step 1: identifying the process constraints – identifying those resources whose productive capacity restricts the system's capacity to meet its product sales flow (the constraint can even be the demand from the market itself);

step 2: exploiting the process constraints – this means getting the most out of them, for instance, not wasting time on machine bottlenecks;

step 3: subordinating everything else to the decisions that regard the constraints – the bottlenecks define the flow of production and the stocks, the use of non-bottleneck resources, among others;

step 4: relaxing the constraint – this means increasing the production capacity of the bottleneck, in the sense of increasing the system's flow capacity;

step 5: if a constraint was relaxed in step 4, go back to step 1 to identify the system's next constraint.

Before applying the previously described decision process, some precautions should be taken first (Goldratt & Cox, 2002):

It is vital to choose a leader for the process, who is in a senior management position, in order to be able to alter certain high-level policies (which may characterize constraints on the system); this person should be totally committed to the firm's goal.

1. The leader should clarify any doubts the group may have.
2. The leader should allow other people to be leaders of other parts of the ongoing improvement process.

3. The leader and the group of managers will be responsible for executing the actions they have planned in the shortest amount of time possible and, therefore, will be responsible for their results.
4. The first action of the leader and the group of managers is to determine the firm's goal and the corresponding indicators.
5. The group's second action should be to identify the firm's constraints and select the one that will produce the fastest result without demanding investments.

There are simple ways to identify the physical constraints and to analyze them in relation to the market's real demand. Physical constraints can include the following: manufacturing constraints, equipment constraints, raw material constraints, input constraints, staff constraints, process constraints and similar elements.

2.2. Policy Constraints

Regarding policy constraints, the TOC offers a three-question methodology, based on a method of scientific thought. In order to implement improvements and changes effectively, three basic questions need to be asked:

1. **What needs to change?**

Not everything needs to be changed; most things are good enough as they are or, alternatively, the profit resulting from changing them does not justify the cost.

2. **Why change?**

Often it is obvious that a process needs to be changed, but it is unclear why it should be changed.

3. **How to change?**

Even if one knows exactly what to change and why this should be changed, one still faces the difficult task of causing the firm to implement the change fully.

However, an even greater difficulty is how to answer these questions, how to treat them and how to encourage them. Moreover, in order to be able to answer these questions in a continually developing environment, it is crucial that certain skills be used as resources enabling one to identify, to find and to induce.

Identifying the key problems of each constraint is quick, to some extent, and the solution seems viable. At the same time, these key problems can be very well hidden, sometimes even by the interested parties themselves. The firm must be able to identify the "root" systematically and not waste time on the "leaves."

Finding practical and simple solutions is essential. Complex solutions are generally not the answer. Simple solutions, on the other hand, can lead to the right solution. The motto should be: *find the simple solution rather than the easy one*.

Inducing the right people to come up with a good solution is the ideal way, especially when it involves changes in the basic assumptions. It is naive to expect people to embrace the solution, even if it seems that it has met with no resistance, because they will not understand it in the way it must be understood for its proper implementation. The only easy and practical way to overcome these obstacles is to encourage the people who will be involved in the implementation of the change to come up with the solutions "by themselves."

2.3. Theory of Constraints Techniques

Once the key skills have been developed, it becomes necessary to eliminate the policy constraints. To achieve this, the basic five-step, three-question TOC technique is applied, as is explained below.

1. Effect–cause–effect (*What needs to change?*)

This technique is neither new nor sophisticated, and its use allows people to reach the core problem quickly. It consists of identifying the root problems, by certifying the cause at each step.

2. Evaporating clouds

This is a technique for generating second-order solutions, i.e., simple and effective solutions that produce excellent results. If a major problem can be regarded as a cloud, this technique allows us, instead of solving the problem, to make it disappear, by finding the most imperfect assumption. In other words, when the problem is major, what one should do is to look for the main thing wrong with the system, making the problem disappear, just as wind carries clouds elsewhere. Smaller problems will appear, which are simpler to resolve.

3. Future reality tree (*Why change?*)

This is a technique for evaluating the chosen solution, finding the possible contingencies and neutralizing them, as necessary, before they occur.

4. The prerequisite tree

This is a technique for identifying and listing the obstacles to the implementation of the new solution, given that, with each solution, we obtain a new reality.

5. Transition trees

This is the final technique, and the one that gives us the strategy that will enable us to implement the solution obtained successfully. This is the stage during which the economic necessities and expected benefits are quantified. It also serves as a route map and a checklist, since it contains the sequence of quantitative and qualitative aspects expected from the solution. This tree can easily be converted into a Gantt graph or a traditional implementation plan.

3. PHILOSOPHY OF THE THEORY OF CONSTRAINTS

Any firm that is interested in improvement faces a number of obstacles, the largest and most significant one being natural resistance to all and any type of change; this resistance is an inherent part of being human. In this context, one can see that:

- any improvement is a change; it is not possible to improve something without change, or as the saying goes, one cannot walk up the stairs without taking one's foot off the previous step;
- any change whatsoever is seen by the majority as a threat to their security, given that it is unknown;
- any threat to safety causes emotional resistance;
- this emotional resistance delays the introduction of improvements.

These factors correspond to the climate perceived within the firm, which is the organizational culture. This provides a solution to some of the problems of disintegration of organizations, by emphasizing the common ideas, ways of thinking, values, standards and ways of working (Freitas, 2009). However, the organizational culture can also be a source of resistance to the process of change and of moving toward competitive advantage, making it stressful to carry out such changes (Standard & Davis, 1999).

To soften this resistance, the TOC diverges from the conventional method of learning, known as the Aristotelian approach. Conventional teaching produces faster results, but its effect does not last for long, which means that the results diminish rapidly. With this type of teaching, one tries to fight emotional resistance with logic. Whenever ones tries to overcome emotion with logic, emotion usually prevails. Successful learning is achieved when it takes place slowly, but continuously, as shown in figure 3 below (Goldratt & Cox, 2002). Therefore, one must arouse a *strong commitment to change*. One must ensure that people enjoy the emotions of a creator, among other reasons because this will enhance their interest in ensuring that the changes are successful.

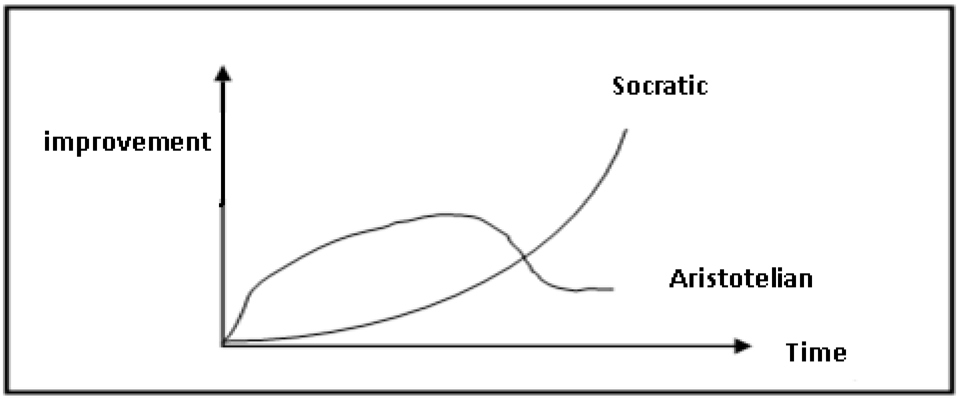

Figure 3. Socratic learning process
Source: Goldratt and Cox (2002).

As a result, the system the TOC disseminates for making learning feasible is the same tried and tested method of old, which has been proven to make people come up with ideas. Socrates employed this strategy when he wanted someone to do something, hence its name: the Socratic approach.

Following this approach, answers are not taught. To the contrary, the person who wants to know something is asked questions and thus forced to discover or invent the answers. Asking Socratic questions is not as simple as it seems. It requires a special methodology and the solutions to be known in advance, broadly speaking. When the questions are poorly conducted, the outcome is merely the irritation of the interested parties. If everyone in the organization understands the firm's basic direction and its goals, then one has a common base and the people involved are more willing to ensure that transformations take place (Standard & Davis, 1999).

Another assumption that the TOC heavily emphasizes is the combination of the two phenomena previously mentioned: *dependent events* and *statistical fluctuations*. In other words, uncertain events will always occur in complex systems, such as production systems. The forecast level of demand is the basis for any firm's strategic plan for production, sales, supplies and finance (Tubino, 2005).

Since it is difficult to anticipate where events will occur, all of the system's fragile or critical points must be protected. Moreover, the production of one item can entail a number of operations in terms of processing and transporting materials.

For most of these, the execution time varies according to a statistical distribution. In other words, the execution time of any given operation varies every time that the operation is performed. This implies that, in the production plan, when processing times (*lead times*) are used for a certain operation, in reality, it is the average *lead times* that are being used, which are subject to statistical fluctuations. Slack (2009) states that stock will occur whenever there is a difference between the pace or the rate of supply and that of demand.

These fluctuations may arise from uncertainties in the operation, equipment capacity limitations, employee negligence, etc. No matter how many measures one establishes to control statistical fluctuations, it is impossible for production systems to eliminate the random component involved in the execution times of several operations. Therefore, in all the production processes, fluctuations exist to some extent, and they affect a substantial part of the operations of a process flowchart, if not all of them.

The fluctuations have roughly a *normal distribution*, given that they result from a series of random or uncontrollable events. If the operations involved in an item's production process were not part of a sequence but were instead isolated, the sum of the fluctuations would tend to be zero. Delays in any particular activity would tend to offset other activities completed ahead of schedule, so that the deviation in the expected average time of execution would tend to zero (Goldratt, 2003).

However, manufacturing involves linking interdependent operations. Therefore, in this case, the chain's statistical fluctuation does not average zero, as delays tend to spread throughout the chain. In other words, we do not have an average fluctuation, but rather an accrual of fluctuations. Moreover, in most cases, we have accrued delay, since the dependence limits the opportunity for greater fluctuations.

According to the logic of dependence between the linked events, the TOC considers that the queue times depend upon how the scheduling is performed. In fact, if a specific production order is given *priority*, for whatever reason, in a queue waiting for a certain operation, this order will spend less time in the queue. As the queueing time is one of the main components of items' *lead times*, not surprisingly, the *lead times* will be different, in accordance with the scheduling of the orders. Consequently, if the lead times result from the scheduling, they should not be used as entry data for the scheduling process.

Thus, the TOC approaches the problem in a different way, simultaneously taking into account the scheduling of activities and the capacity of bottleneck resources. Taking into account the capacity constraints of the bottleneck resources, the system decides to prioritize their occupation, and based on the defined sequence, calculates the lead times, which allows it to schedule the production better.

For effective, optimum use of this theory, one should resort to its nine principles, which organize manufacturing management actions (Goldratt & Cox, 2002). These nine principles are set out below.

1. Balance the flow rather than the capacity

The traditional approach is to balance the capacity and then try to establish a gentle and if possible continuous flow of materials. The TOC argues against balancing the capacity and favors balancing the firm's production flow. It is not capacity that should be balanced relative to demand. Instead, it is necessary to balance the flow of a product through the factory with the market's demand. The idea is to make the flow through the bottleneck equal to the demand, since it is the first of these items that will limit the flow of the system as a whole.

2. The use of a non-bottleneck resource is not determined by its availability, but by some other restriction of the system

The use of the non-bottleneck resource should be determined by one of the system's constraints, by the bottleneck resource or by the market demand.

3. Use and activation of a resource are not synonymous

There are crucial distinctions between using and activating a resource. Activating a non-bottleneck resource more than enough to feed a limiting bottleneck resource does not contribute to the defined objectives. To the contrary, the flow would remain constant though limited by the bottleneck resource. Meanwhile, the level of stock would rise, as would operating expenses, due to having to manage the ensuing stock. Since, in this case, the activation of the resource does not imply helping the firm to achieve its targets, it cannot be called resource use, only activation.

4. One hour gained regarding a bottleneck resource is one hour gained for the entire system

The time available in a bottleneck resource is split between two components: processing time and preparation time. In the case of a bottleneck resource, if an hour of preparation time is saved, then an hour is gained in terms of processing time; in other words, the bottleneck resource becomes available for processing material. Moreover, one hour gained for processing in a bottleneck resource is not just a one-hour gain in the resource in question, but a one-hour flow gain for the entire production system, as it is this resource that limits the flow capacity of the system as a whole.

5. One hour gained in relation to a non-bottleneck resource is not a gain at all: it is just a mirage

By definition, the time available of a non-bottleneck resource consists of three components: *preparation time, processing time* and *idle time*. Therefore, one hour of preparation time saved in relation to a non-bottleneck resource merely represents another hour of idle time for this resource, since the amount of processing time in the case of a non-bottleneck resource is determined not by its availability, but by some other constraint on the system.

6. The transfer lot need not be and, frequently, should not be equal to the processing lot

In the TOC, the transfer lot is always a fraction of the processing lot. This is the size of the lot that will be processed of a resource before it is prepared again for the processing of another item. The transfer lot meanwhile is the definition of the size of the lots that will be transferred to the subsequent operation. Since under the TOC these lots are not required to be the same size, amounts of processed material can be transferred to a subsequent operation, even before all the material in the processing lot is processed. This allows the lots to be split, enabling a reduction in the time that products spend going through the factory.

7. The processing lot should be variable rather than fixed

In the TOC, contrary to what occurs in most traditional systems, the size of processing lots is a function of the factory's situation and may vary from operation to operation. These lot sizes are established by the theory's calculation system, which takes into account the cost of carrying stocks, preparation costs, the flow requirements of certain items and the types of resources, among others.

8. The bottlenecks determine not only the system's flow, but also its stocks

The bottlenecks define the production system's flow, because they are the limiting factors for capacity. However, they are also the main factors that determine the level of stocks, because these have their volume determined and are located at points that can isolate the bottlenecks of statistical fluctuations spread by the non-bottleneck resources that feed them. For instance, one builds up stock before the bottleneck machine, so that any delay does not lead to a stoppage of the bottleneck because of a shortage of material. This is achieved by creating a time cushion before the bottleneck resource. In other words, the materials are scheduled to arrive at the bottleneck resource a specific amount of time before the instant at which the bottleneck is scheduled to become operational.

9. The scheduling of activities and productive capacity should be considered simultaneously rather than sequentially. The *lead times* result from scheduling and cannot be assumed *a priori*

As illustrated above, the queue times are a consequence of the scheduling and of the priorities scale. In this context, the *lead times* are consequences rather than assumptions.

4. THE APPLICATION OF THE TOC IN THE SMALL METALLURGICAL COMPANY

The small metallurgical plant located in the city of Campo Limpo Paulista/SP (Brazil), introduced the TOC as a work philosophy and successfully applied the theory's principles to its manufacturing process. Using the efficiency of the TOC, it was noticed how its directors decided how and where they should invest its money.

Below, we show a simple example from the company from among its many manufacturing processes. To simplify the demonstration and make it easier to understand, the real figures have been adjusted and reorganized, under the assumption that the firm only manufactures two products, which will be referred to as product P and product T (see chart 1).

Selling price of product P	U$ 200.00 per unit
Selling price of product T	U$ 150.00 per unit
mp3 is a product purchased on the market	U$ 20.00 per unit
Cost mp1	U$ 60.00 per unit
Cost mp2	U$ 30.00 per unit
Operating expenses	U$ 160,000.00 per week

Chart 1. Financial figures
Source: Research figures.

In addition, it was assumed that the market demand is just 2,000 units of P and 1,000 units of T a week.

Manufacturing sectors	"a," "b," "c," "d"
Weekly hours	40 hours per sector
Part mp1 goes through sectors	"a" and "c"
Part mp2 goes through sectors	"b" and "c"
Parts mp1, mp2, mp3	Assembled in sector "d"
Part mp3 goes through sectors	"a" and "b"
Product P is made up of:	Parts mp1, mp2 and mp3
Product T is made up of:	Parts mp2 and mp3

Chart 2. Factory sectors
Source: Research figures.

As for any firm that tries to maximize its profits, the question considered by the manufacturer was how many units of each type should be produced in order to obtain the highest possible profit, in accordance with the figures shown in charts 1, 2 and 3.

Parts	MINUTES			
	Sector A	**Sector B**	**Sector C**	**Sector D**
Part mp1	25	0	25	0
Part mp2	0	20	10	0
Part mp3	20	30	0	0
Parts mp1+mp2+mp3	0	0	0	20
Parts mp2+mp3	0	5	0	10

Chart 3. Manufacturing times
Source: Research figures.

Under the conventional planning system of the company's production, this program was configured to make use of the full load of all the machines, with the results obtained being in accordance with what is shown below. The initial action taken was to manage the constraints and, by identifying the system's constraints, to calculate the process load, the breaks and the set-ups, as shown in chart 4. Here, we assumed that there were no set-ups and no interruptions.

RESOURCES (Sectors)	TIME Available/week (minutes)	PROCESS Load/week (minutes)	USE Percentage
A	96,,000	mp1 (25×2,000)=50,000 mp3 (10×1,000)=10,000 **total=60,000**	63%
B	96,,000	mp3 (30×2000)=60,000 mp2 (20×1,000)=20,000 mp3 (20×1,000)=20,000 mp2+mp3(5x1,00)=5,000 **Total=105,000**	110%
C	96,,000	mp1 (25×2,000)=50,000 mp2 (10×2,000)=10,000 mp2 (10×1,000)=10,000 **Total=70,000**	73%
d	96,,000	P (20×2,000)=40,000 T (5×1,000)=5,000 **Total=45,000**	47%

Chart 4. Production volume *versus* capacity
Source: Research figures.

According to chart 5, one can see that the system's constraint is sector "b" and conclude that it will be impossible to manufacture everything that the market buys, so the firm will have to choose the best parts and the best amounts to sell. Therefore, the problem is knowing which parts it will manufacture and in what numbers. Using the conventional approach, one obtains the result shown in chart 5.

FIGURES	PRODUCT ***P***	PRODUCT ***T***
Selling price (U$)	200.00	150.00
Raw materials cost (U$)	110.00	70.00
Contribution margin (U$)*	90.00	80.00
Processing time (minutes)	110	70
Cost/minute of piece (U$)**	0.82	1,14
* selling price – raw materials cost ** selling price – raw materials cost		

Chart 5. Figures that make up the contribution margin
Source: Research figures.

Therefore, according to chart 6, the best product for the firm to produce is T, which generates a profit of U$ 0,89 for every minute of processing in the factory. Based on the best product and its profit per minute of processing, the firm should produce the maximum number of units of product T, which corresponds to 1,000 units a week. The available operating time, in other words the remaining capacity, will be used to manufacture product P, due to the constraint in department "b." Chart 6 shows the calculation of the maximum profit using the conventional approach, which gives us a loss of U$ 6,500.00 a week.

PRODUCT ***T***	
Market	1,000 pieces/week
Contribution margin U$	80.00 (150-70)
Total time utilized in "b"	45,000 minutes
Amount of time remaining in "b" (for **P)**	51,000 minutes
Gross profit with T (1,000 pieces×U$ 80) U$	**80,000.00**
PRODUCT ***P***	
Market	2,000 pieces/week
Contribution margin R$	90.00 (200-110)
Capacity in function of "b" (51,000/60)	850 pieces/week
Gross profit with P (856 pieces×U$90) U$	**73,500.00**
Total gross profit (T+P) U$	153,500.00
Operating expenses R$	(160,000.00)
Net profit/week R$	**(6,500.00)**

Chart 6. Maximum profit using the conventional approach
Source: Research figures.

Under the TOC approach, the objective is to maximize profit; according to chart 4, the TOC indicated that the constraint is sector "b." Using this element, we construct chart 7, which shows the best cost per minute under this constraint.

FIGURES	PRODUCT ***P***	PRODUCT ***T***
Selling price (U$)	200.00	150.00
Raw materials cost (U$)	110.00	70.00
Contribution margin (U$)*	90.00	80.00
Processing time (minutes)**	30	45
Cost/minute under the constraint (U$) ***	3,00	1,78

* selling price – raw materials cost ** time of mp2+mp3 *** selling price–raw materials cost

Chart 7. Figures that make up the best contribution margin
Source: Research figures.

Therefore, according to chart 8, the best product for the firm to produce is P rather than T, which was indicated using the conventional approach. Based on the focus that is most compatible with the analyzed context, the Theory of Constraints, the small manufacturing should produce 2,000 units of product P and the remaining time should be used to manufacture product T, in light of the constraint observed in sector "b." Chart 8 shows the best profit that can initially be obtained.

PRODUCT ***P***	
Market	2,000 units/week
Contribution margin (R$)	90.00 (200-110)
Total time utilized in "b"	60,000 minutes
Amount of time remaining in "b" (for **P)**	36,000 minutes
Gross profit with P (2,000 units×U$90) U$	**180,000.00**
PRODUCT ***T***	
Market	500 units/week
Contribution margin (R$)	80.00 (150-70)
Capacity in function of "b" (36,000/45)	800 units/week
Gross profit with T (800 units×U$80) U$	**64,000.00**
Total gross profit (P+T) U$	244,000.00
Operating expense U$	(160,000.00)
Net profit/week U$	**84,000.00**

Chart 8. Calculation of the best profit using the TOC
Source: Research figures.

According to chart 8, the best profit that can be obtained is the one shown, i.e., U$ 6,500.00 a week. This results from the comparison of the two alternatives assessed in terms of weekly profit maximization, as per charts 7 and 8; according to the conventional approach, chart 7 showed a U$ 6.500.00 loss, and following the TOC approach, chart 8 showed a U**$ 84,000.00** profit. In this particular case, a decision was made to calculate which product mix yielded the greatest profitability in the face of one constraint: **lack of**

capacity in "b." The above exposition makes it clear that the constraint determines profitability, and therefore that one should always use the constraints to achieve the highest profit.

5. FINAL THOUGHTS

As has been shown, the TOC acts preventively and effectively, by controlling the effects and eliminating the causes of constraints, without affecting the flow, by using the existing capacity to supply the demand. This theory is compatible with any type of firm and market, because it manages the bottlenecks and cushions that affect the production flow, subordinating all the other activities to the constraints and ensuring an increase in value added.

The TOC is especially useful for helping firms to reduce their *lead times* and stock levels. Based on surveys among firms that use this theory as well as on the results obtained from the small manufacturing, one can conclude that users of this theory report reductions in the lead times of their processes of the order of 30 to 45% and, in relation to their stocks, decreases of between 50 and 75%. This system also results in greater flexibility of the production system through an optimization of the manufacturing mix.

Although the empirical observation base may be considered too small to make recommendations about the widespread use of the TOC, one should bear in mind that the case study used in this article included questions involving factors found in most small firms. Comparing the production chain of the firm studied with others, one finds that there is a great deal of similarity to other small manufacturers in Brazil.

The TOC helps firms focus their attention on their problems. Because it regards bottleneck resources as being worthy of special attention and since, in general, there are few bottlenecks, firms are encouraged not to waste their efforts, but rather to concentrate on solving the problems that may jeopardize the performance of these bottleneck resources, which in turn jeopardize the operating result of the business as a whole.

The TOC principles offer new insights into old problems. These work towards a better understanding of these problems and encourage a search for new solutions. The Socratic method used causes the idea of “belonging” to the individuals who are going to put the solution into practice rather than to those who idealized the change. The important issue is to overcome the general resistance to change and ensure that everyone feels that they too helped spawn the invention.

One can also infer that firms, even under similar conditions, resort to different means to compete, and that their current strategic alignment can be focused on the elimination of constraints as a strategic differential.

There are several possibilities for developing this line of research further, such as: a) a comparison of small industrial firms, to generate further empirical elements for comparing organizations; b) a study involving firms from different economic sectors; c) comparative studies aimed at identifying the differences in production strategies due to different areas of activity.

In addition, other possible surveys could aim to analyze the elements portrayed here in greater depth to explore these issues in detail, how operating elements combine in the context of the management of small firms and the way in which these elements support their competitive strategies based on the use of TOC.

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