ARTICLES

THE THEORY OF CONSTRAINTS AND THE SMALL FIRM: AN ALTERNATIVE STRATEGY IN THE MANUFACTURING MANAGEMENT

Hamilton Pozo
Pós-Doutor em Administração pela Universidade de São Paulo – FEA/USP
Coordenador e Pesquisador no Projeto de implantação de mestrado profissional na Faculdade Campo Limpo Paulista – FACCAMP
E-mail: **hprbrazil@yahoo.com** [Brasil]

Elio Takeshi Takeshy Tachizawa
Doutor em Administração de Empresas pela Fundação Getúlio Vargas – FGV
Professor da Faculdade Campo Limpo Paulista – FACCAMP
E-mail: **usptakes@uol.com.br** [Brasil]

Djair Picchiai
Doutor em Administração de Empresas pela Fundação Getúlio Vargas – FGV
Professor da Fundação Getúlio Vargas – FGV e professor da Faculdade Campo Limpo Paulista – FACCAMP
E-mail: **djair.picchiai@fgv.br** [Brasil]

Abstract

The aim of this article is to study the practical application of the Theory of Constraints (TOC) and to identify some of the main strategies related to this application. 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. TOC shows that every system is subject to at least one constraint that keeps it from achieving high levels of performance. A study of the use of TOC in a small manufacturing firm and the results obtained are shown here. This use made it possible to identify the constraints, and thus to improve the firm performance and productivity.

Keywords: Theory of constraints, strategic differentials, productivity. Manufacture, small firm.

RAI – Revista de Administração e Inovação
ISSN: 1809-2039
Organização: Comitê Científico Interinstitucional
Editor Científico: Milton de Abreu Campanario
Avaliação: Double Blind Review pelo SEER/OJS
Revisão: gramatical, normativa e de formatação

1 INTRODUCTION

The Theory of Constraints, known as TOC, can be defined as a procedure for managing factors, production processes, organizational decisions and situations in which there are constraints in the present state. 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 that its ongoing improvement process continues unabated.

The Theory of Constraints 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 prevents it from achieving optimal performance. By using the Theory of Constraints, 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 production capacity.

TOC claims that a real-world system with more than three constraints is extremely unlikely. This claim is based on linear programming models, which are capable of solving optimization problems for systems with many hundreds of constraints. Researchers found that all but a few such solutions were so unstable that they would be completely impractical amid the noise of a real-world system. Stability had a strong correlation to the number of constraints -- the more constraints, the less stability. TOC practitioners claim that in practice three constraints is the realistic maximum.

A major implication of this is that managing a complex system or organization can be made both simpler and more effective by providing managers with a few specific areas on which to focus -- maximizing performance in the areas of key constraints, or **elevating** the constraint (making it less constraining). This also leads to a strategic view of the company where the constraint guides all strategic decisions.

Another key concept of the Theory of Constraints is that variation (in production and material transfer times) prevents the operation of a balanced factory at 100 percent capacity. This concept is illustrated in Goldratt and Cox (2002) by a matchsticks-and-dice simulation in which the players represent production stations. At each turn, each player passes the lesser of his dice roll (his station's capacity for that turn) and the number of matchsticks he has (work waiting at his station) to the next person. Although each station has a theoretical average capacity of 3.5 units per turn, the simulated factory overall production is somewhat less because high die rolls, which are wasted when no work is available, do not make up for the low ones. These are the original Goldratt **process of ongoing improvement** steps to identify, exploit and manage the system's constraints, whether the system is manufacturing, distribution, sales, or project management.

1. Identify the system's constraint(s).
2. Decide how to exploit the constraint(s).
3. Subordinate everything else to the above decision.
4. Elevate the constraint.
5. If, in any of the above steps, the constraint has been broken, go back to Step 1.

TOC can be used on three different levels:

Level 1: production management – to solve bottlenecks, production scheduling and reduction of inventories problems;
Level 2: process analysis - application based on the direct costing method, instead of traditional cost analysis, making it possible to base measures taken on the ongoing improvement of processes, system improvements and systems' constraints that, in statistical terms, determine protective capacities, critical points and their key elements;
Level 3: general application of TOC, aimed at tackling a variety of processing problems within the organization, by applying its logic in order to identify which factors are preventing the organization from achieving its targets, developing a solution to the problem of ongoing improvement.

As a new scientific manufacturing management methodology, the main objective of TOC is to promote ongoing optimization of the expected performance in any organization that has a well-defined **goal**, by focusing 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 the customer's needs. It should be clear that for an industrial organization to increase its performance and its productivity and thus raise profits, the production flow should be optimized at **factory floor** level, while stocks should also be drastically reduced, thus lowering operating expenses.

2 TOC 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 order to achieve ongoing improvement. The organization must use **straightforward and ordinary** language, thus avoiding the frequent communication problems that exist in the business environment. In a conventional system, evaluating the performance of a manager means checking to see whether or not s/he has achieved the company's objective. It is necessary to evaluate the result at the end of the period as regards the following factors: production achieved, net profit, cash flow and return on investment, along with other such items. However, this is only done afterwards. TOC provides a tool for evaluating the result of the process before, during and after it runs (GOLDRATT; COX, 1987, 1988, 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 product. And operating expenses are all the financial resources necessary to turn the materials (I) into throughput (VA). Manufacturing management must keep a market oriented approach in mind, because profits come from the **value added** resulting from sales rather than 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 inventory levels and make production more flexible, with a more linear flow, and avoiding interruptions to the production process.

According to Goldratt (2003), the organization will improve its overall performance through manufacturing performance 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, 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 of corporate stock levels, with the consequent reduction of the firm' s operating expenses, resulting in an optimized decision for the business as a whole. 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 (BLACK, 1991; PLUTE, 1998; SHINGO, 1987; TOONEY, 1996). TOC greatly reduces business costs. This becomes clear when the theory's assumptions are compared to the application of cost accounting principles (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, TOC virtually eliminates the use of Economic Order Quantities (EOQ) and production lots (GOLDRATT; COX, 2002).

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

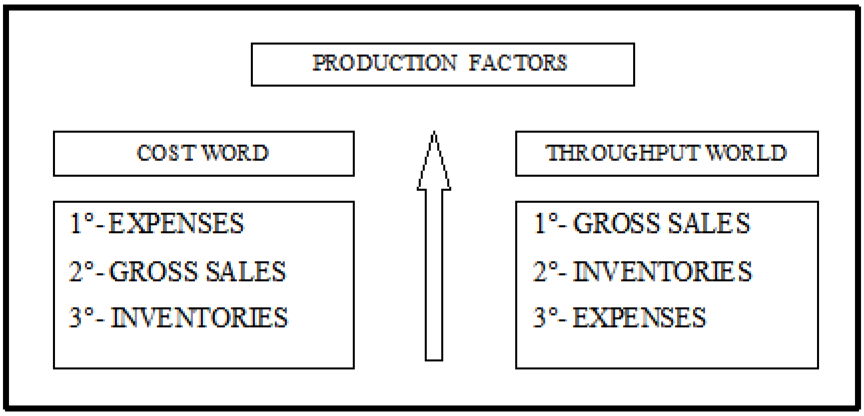

Figure 1 - Conventional cost accounting and cost accounting by means of throughput
Source: Authors' adaptation (GOLDRATT; COX, 2002)

TOC, like Cost Accounting, regards firms as a sequence of events. Cost accounting, however, tries to reduce costs in all of a firm's productive segments. On the other hand, 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 constraints, manufacturing management controls the contribution margin and the unit production cycle with regard to 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).

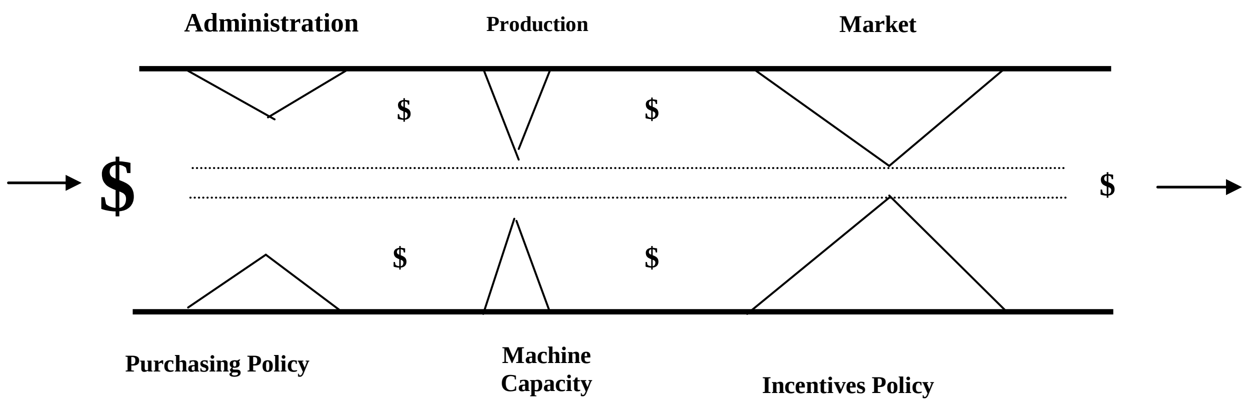

Figure 2 - Simplified diagram of the critical constraints.
Source: Goldratt and Cox (2002)

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 a such 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 in 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 termed **dependent events** whereas the other is known as **statistical fluctuations**. In order to obtain ongoing improvement in the case of physical constraints, TOC establishes a five-step Decision Process (GOLDRATT; COX, 2002):

Step 1: identifying the process constraints – identifying those resources whose productive capacity restricts the system's capacity to guarantee its 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 resource, 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 in step 4 a constraint was relaxed, go back to step 1 to identify the system's next constraint.

Before applying the previously described Decision Process, some precautions should be taken (GOLDRATT; COX, 2002). It is vital to choose a leader for the process, someone 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 real demands of the market. 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, TOC offers a three-question methodology, based on a method of scientific thought. TOC processes used to improve the health of an organization (or solve any problem) are almost identical; however, the terminology is changed to better suit the language of problem-solving in organizations (GOLDRATT, 2007). In TOC, the process is described via the use of three questions: **What needs to Change?, Why Change?, and How to Cause Change?** 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 cause change? -** even if one knows exactly what to change and why this should be changed, one still faces the difficult task of getting the firm to fully implement the change.

However, an even greater difficulty is how to answer these questions, how to deal with 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 very 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 systematically identify the **root** 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 it, even when it seems that it has met with no resistance, because they will not understand it in the way it must be understood for 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

The key elements of TOC are any company should be able to **make more money now and in the future.** Putting it another way, profit is not a bad word, but every process has constraints, which prevent it from operating at the highest level possible. These problems must be identified and fixed. Throughput, or increasing production output, is the main focus of TOC and everyone must strive to constantly increase good castings. It involves others in the improvement process. The only real improvements are permanent improvements.

The core of TOC is that for any given system, at any given time, there will be at least one constraint on that system, determining how quickly the system can produce. TOC, applied to manufacturing, seeks to identify bottlenecks in the production line. The underlying assumption is that a production facility is only as fast as the slowest process in the chain. As a general rule, TOC assumes that a value chain is only as strong as the weakest link in the chain. The capacity of the weakest link is the current system constraint (ANDERSON, 2006). TOC is a systems approach that looks at every part of a system, from concept to cash. Individual steps are not considered to be of highest priority – that is, TOC does not optimize a single step in a system to ensure that this single step is working to its full capacity. Instead, TOC‘s primary focus is to maximize the throughput of a system. With the knowledge of the system’s constraints, it seeks to increase the production capabilities of that system, while reducing the cost of production and shortening production time.

There are a few high level categories of metrics that can be found in TOC, like production metrics and financial metrics. Production metrics help us to measure how much we are producing and how quickly we are producing it. The financial metrics use the production data to tell us the cost and profit of the process that we are producing that a single feature or end-user function and is how we are tracking the development efforts. This is only one way of tracking, though. There is additional discussion on applying the metrics of TOC for others manufacturing system.

Throughput accounting is also a systems approach – it examines the entire cost structure of a system, from concept to cash. This is in direct opposition to standard cost-accounting systems, which seek to maximize the production rate of single steps in a given system, with no regard for the production capacity of the entire system. The goal of applying Throughput Accounting with TOC is to increase the throughput of the system while decreasing the inventory and investment, and decreasing the operating expenses of that system. At this point, there is no real need to distinguish between TOC and Throughput Accounting.

The thinking processs that has been termed throughput accounting suggests that one should examine the impact of investments and operational changes in terms of the impact on the throughput of the business. It is an alternative to cost accounting to help managers walk through the steps of initiating and implementing a project. When used in a logical flow (DETTMER, 2007), the Thinking Processes help walk through a buy-in process. Once the key skills have been developed, it becomes necessary to eliminate policy constraints. To do 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 get to the core problem quickly. It consists of identifying the root problems, by ascertaining 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 a major one, what we should do is look for the main wrong thing 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 get a new reality.

5. Transition Trees: This is the final technique, and it is the one that gives us the strategy that will enable us to successfully implement the solution found. This is the stage at 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 be easily converted into a Gantt Graph or a traditional Implementation Plan.

3 PHILOSOPHY OF THE THEORY OF CONSTRAINTS

Any firm that is very 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 - we 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 atmosphere in the firm, which is the organizational culture. This provides the solution to some of the problems of disintegration of organizations, by emphasizing common ideas, ways of thinking, values, standards and ways of working (FREITAS, 1991). However, organizational culture can also be a source of resistance to the process of change, of moving toward competitive advantage, making it stressful to carry out change (STANDARD; DAVIS, 1999).

To soften this resistance, TOC diverges from the conventional method of learning, known as the Aristotelian approach. Conventional teaching produces faster results, but its effect does not last long, which means that the results rapidly diminish. With this type of teaching, one tries to fight emotional resistance with logic. However, 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 (GOLDRATT; COX, 2002). Therefore, one must arouse a **strong commitment to change**. One must ensure people enjoy a creator's emotions because, among other reasons, this will enhance their interest in ensuring the changes work out.

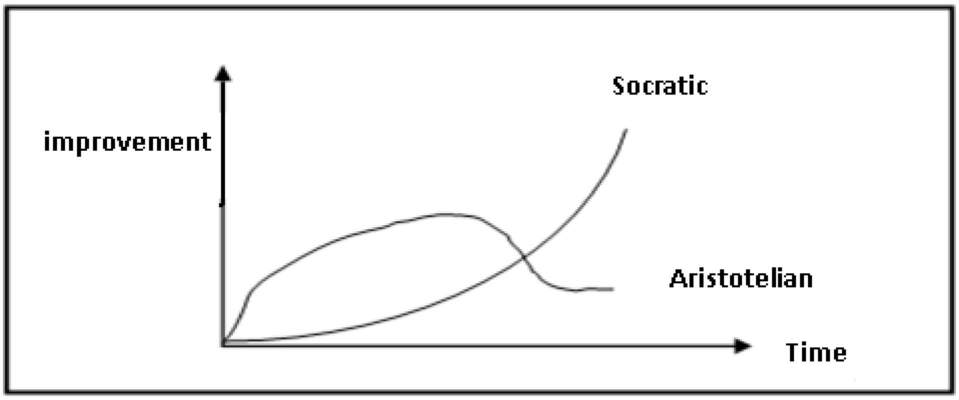

Figure 3 - Socratic learning process
Source: Goldratt and Cox (2002)

As a result, the system that TOC disseminates in order to make earning feasible is the same true and tried 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.

Under this approach, answers are not taught. On 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 that the solutions 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 basic direction of the company 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).

In order to schedule activities with the aim of achieving objectives, TOC assumes that it is first necessary to have a thorough understanding of the interrelationship between two types of resources usually found in every organization: bottleneck resources and non-bottleneck resources. Consider **bottleneck resource** X and assume that total market demand implies a monthly use of 200 monthly hours of this resource. In addition, as this is a bottleneck resource, it is assumed that demand is equal to the availability of this resource, in other words, 200 hours a month. By definition, the bottleneck resource is entirely utilized during the entire time of its availability. The demand for another **resource** Y, which is a non-bottleneck resource, comes to a total of 150 hours/month, although, like resource X, it has a production capacity of 200 hours (see Figure 4).

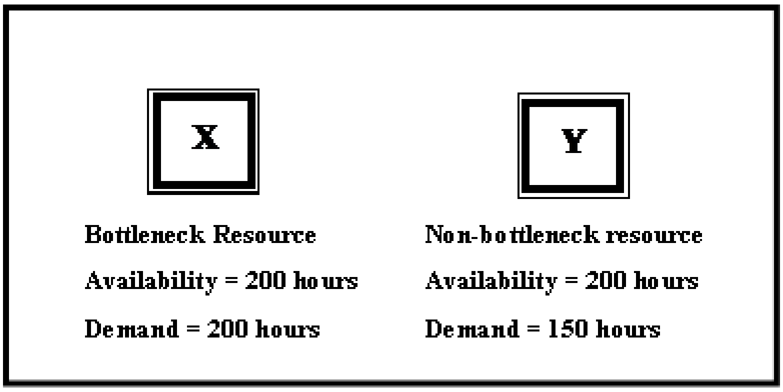

Figure 4 - Bottleneck and non-bottleneck resources
Source: Authors' adaptation (GOLDRATT; COX, 2002)

With regard to the resources and the demands shown in figure 4, one may state that there are four types of relationships possible between these two resources.

The first of these is when all production flows from resource X to resource Y. In this situation, one can fully (100%) utilize resource X, but only 75% of resource Y's available time can be used, because resource X cannot produce enough to keep resource Y busy the whole time, as is shown in Figure 5.

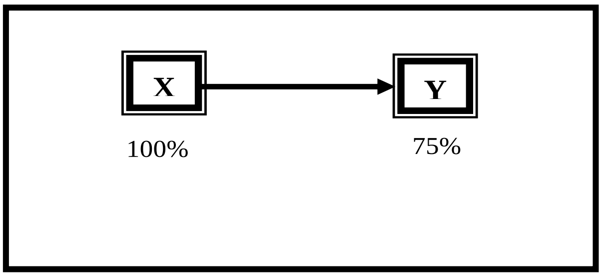

Figure 5 - Flow of resource X to Y
Source: Authors' adaptation (GOLDRATT; COX, 2002)

A second relationship, illustrated in Figure 6, occurs when production flows from Y to X. Resource X will be used 100% of the time, and resource Y can be activated 100% of the time, as long as there is raw material available. However, bearing in mind that one of the TOC objectives is to increase flow while also reducing stock and operating expenses, the conclusion is that Y should only be activated 75% of the time. Any activation, over and above this, implies in the build up of stocks in process, between resources Y and X, without any increase in flow, which is limited by X.

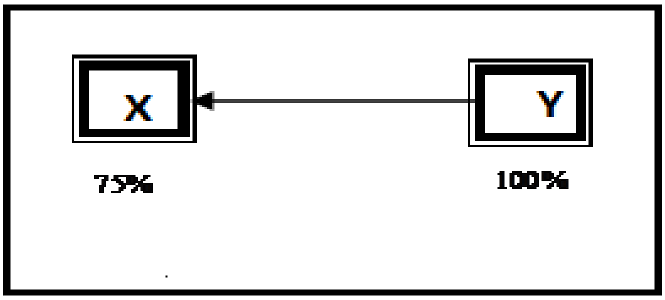

Figure 6 - Flow of resource Y to X
Source: Authors' adaptation (GOLDRATT; COX, 2002)

The third relationship occurs when resources X and Y, instead of feeding each other, feed an assembly system that uses the parts through both. Resource X can be used 100% of the time. However, if resource Y is activated for more than 75% of the time, stock of this item will build up before it is assembled, since it is limited by the production capacity of resource X, as illustrated in Figure 7.

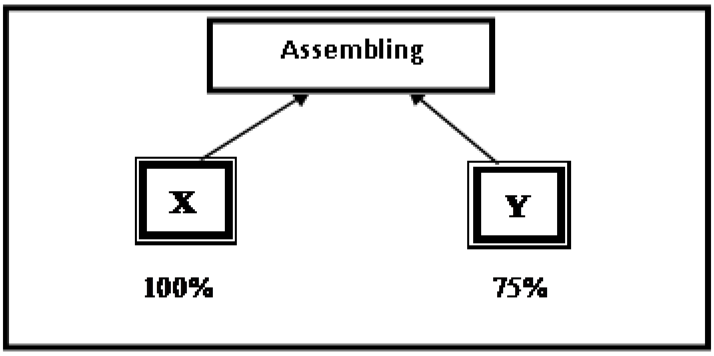

Figure 7 - Flow of resources X and Y for the assembling process
Source: Authors' adaptation (GOLDRATT; COX, 2002)

The last type of relationship that can involve the two resources is when they neither feed a common assembly system, nor feed each other. Instead, they feed independent market requirements. Once again, resource X can be used 100% of the time, but resource Y can only be used 75% of the time, otherwise it will lead to a build-up of stock of finished products. This is because demand remains limited and, to meet it, resource Y only needs 75% of its total processing capacity (150 hours a month), as is shown in Figure 8.

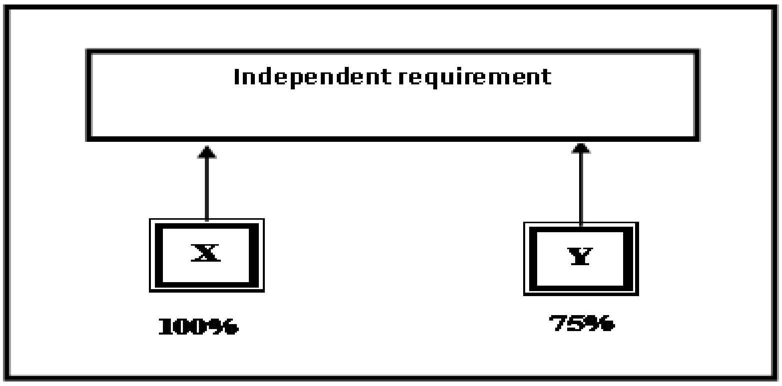

Figure 8 - Flows of resources X and Y with independent demand
Source: Authors' adaptation (GOLDRATT; COX, 2002)

Another assumption that 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 (2002) states that stock will occur whenever there is a difference between the pace or the rate of supply and of demand.

These fluctuations may arise from uncertainties in the operation, equipment capacity limitations, employee negligence, etc. No matter how much one establishes measures to control statistical fluctuations, it is impossible for production systems to eliminate the random component involved in the execution times of the several operations. Therefore, in all 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 it results 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 statistical fluctuation of the chain does not average zero, as delays tend to spread throughout the chain. In other words, we do not have an average fluctuation, but rather a fluctuation accrual. Moreover, in most cases, we have accrued delay, since the dependence limits the chances for greater fluctuations.

According to the logic of dependence between the linked events, TOC considers that the queue times depend upon how the scheduling is done. In fact, if a specific production order is given **priority,** for whatsoever reason, in a queue, waiting for a certain operation, this order will spend less time in the queue. As the queue time is one of the main components in 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, 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 better schedule production.

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 capacity and then try to establish a gentle and if possible continuous flow of materials. TOC argues against balancing capacity and favors balancing the production flow. It is not capacity that should be balanced relative to demand. Instead, it is necessary to balance the flow of product through the factory with market demand. The idea is to make the flow through the bottleneck equal to 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 constraints, by the bottleneck resource or by 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. On the contrary, the flow would remain constant though limited by the bottleneck resource. Meanwhile, the level of stock would rise, as would operating expenses, owing to the fact that it is necessary 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, but only activation.

4. One hour gained in relation to a bottleneck resource is a one-hour gain 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 TOC, the transfer lot is always a fraction of the processing lot. This is the size of the lot that will be processed in a resource before it is prepared again for the processing of another item. The processing lot is the definition of the size of the lots that will be transferred to the subsequent operation. Since under 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 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 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 not only determine the system flow, but also its stocks

The bottlenecks define the production system 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 from statistical fluctuations caused by 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 at 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 in a specific period of time before the instant at which the bottleneck is scheduled to go into operation.

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. In this context, the **lead times** are consequences rather than assumptions.

4 CASE STUDY OF THE APPLICATION OF TOC AT THE FRENIX ORGANIZATION

The car parts firm **Frenix Friction Materials** introduced TOC as a work philosophy and successfully applied the theory principles to its manufacturing process. The firm, taking advantage of TOC efficiency, observed the way directors decided how and where they should invest its money.

Frenix Friction Materials, situated in Sorocaba, in the state of São Paulo, Brazil, is a small auto part plant that used the Theory of Constraints (TOC) to create an industry powerhouse. In a commodity business, with a small participation in the friction materials market, producing at the rate of 45 to 60 thousand units per month, TOC transformed an 8-year-old plant from industry follower to shining star. In one year, throughput grew at 48% while the industry grew at an average rate of 9 to 12%. Inventory turns went from four to eleven (industry average is six) and they are headed to 10. In two years, the plant went from no profit to 39% of the friction materials.

When the owner of the Frenix decided to invest R$ 25 thousand in a new manner of manufacturing management, using the TOC principles, was created the best group in the plant to implement and manage the project. One of the first tasks for the project team was to go through the traditional system to the new process. Following critical chain methods, the team made some important decisions along the way, all the employees needed to run the plant were hired and fully trained before the end of building construction, months before the start of production.

Below, we show a simple example from Frenix chosen among its many manufacturing processes. To simplify the demonstration and make it easier to understand, the real figures were 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	R$ 90.00 per unit
Selling price of product T	R$ 100.00 per unit
Product P is made up from one	R$ 5.00 per unit
part purchased on the market and	
from two other parts produced	
in-house (mp1 and mp2)	
Cost mp1	R$ 20.00 per unit
Cost mp2	R$ 20.00 per unit
Operating expenses	R$ 6,000.00 per week

Chart 1 - Financial figures
Source: Developed by the authors

In addition, it was also assumed that market demand is just 100 units of P and of 50 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 and pc	Assembled in sector "d"
Part mp3, goes through sectors	"a" and "b"
Product T is made up of:	Parts mp2 and mp3

Chart 2 - Factory Sectors
Source: Developed by the authors

As with any firm that tries to maximize profits, the question put to 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.

MANUFACTURING TIME	MINUTES	SECTOR
Part mp1	15	a
Part mp1	10	c
Part mp2	15	b
Part mp2	5	c
Parts mp1 + mp2 + mp3	10	d
Part mp3	10	a
Part mp3	15	b
Parts mp2 + mp3	5	d

Chart 3 - Manufacturing Times
Source: Developed by the authors

Under the conventional planning system of Frenix'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 constraints, to calculate the process load, the breaks and the set-ups, as shown in Chart 4. Here, we assumed there were no set-ups and no interruptions.

RESOURCES	TIME	PROCESS	USE
(SECTORS)	AVAILABLE/	LOAD/WEEK	PERCENTAGE
	WEEK (MINUTES)	MINUTES	
		mp1 (15x100) =1,500	
A	2,400	mp3 (10x50) = 500	
		Total = 2,000	83%
		mp3 (15x100) = 1,500	
		mp2 (15x50) = 750	
B	2,400	mp3 (15x50) = 750	
		Total = 3,000	125%
		mp1 (10x100) = 1,000	
		mp2 (5x100) = 500	
C	2,400	mp2 (5x50) = 250	
		Total = 1,750	73%
		P (10x100) = 1,000	
d	2,400	T (5x50) = 250	
		Total = 1,250	52%

Chart 4 - Production volume *versus* capacity
Source: Developed by the authors

According to Chart 5, the system constraint is sector "b" and one can 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 optimum quantity to sell. Therefore, the problem is knowing which parts it will manufacture and in what numbers. Using the conventional approach, one gets the result shown in Chart 5.

FIGURES	PRODUCT *P*	PRODUCT *T*
Selling Price (R$)	90.00	100.00
Raw Materials Cost (R$)	45.00	40.00
Contribution Margin (R$) *	45.00	60.00
Processing Time (minutes)	55	50
Cost/minute of piece (R$) **	0.82	1.20
* selling price – raw materials cost		
** selling price – raw materials cost		

Chart 5 - Figures that make up the contribution margin
Source: Developed by the authors

Therefore, according to Chart 6, the best product for the firm to produce is T, which generates a profit of R$ 1.20 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 50 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 R$ 300.00 a week.

PRODUCT *T*		
Market		50 pieces/week
Contribution Margin	R$	60.00 (100 - 40)
Total time used in "b"		1,500 minutes
Amount of time remaining in "b"(for **P)**		900 minutes
Gross profit with T (50 pieces x R$60)	R$	**3,000.00**
PRODUCT *P*		
Market		100 pieces/week
Contribution Margin	R$	45.00 (90-45)
Capacity in function of "b" (900/15)		60 pieces/week
Gross profit with P (60 pieces x R$45)	R$	**2,700.00**
Total Gross Profit (T + P)	R$	5,700.00
Operating expenses	R$	(6,000.00)
Net profit/week	**R$**	**-300.00**

Chart 6 - Maximum profit using the conventional approach
Source: Developed by the authors

With the TOC approach, the objective is to maximize profit; according to Chart 4, TOC indicated that the constraint is sector "b". Using this element, we construct Chart 7, which shows the best cost per minute taking this constraint into consideration.

FIGURES		PRODUCT ***P***	PRODUCT ***T***
Selling Price	R$	90.00	100.00
Raw Materials Cost	R$	45.00	40.00
Contribution Margin *	R$	45.00	60.00
Processing Time (minutes) **		15	30
Cost/minute under the constraint ***	R$	3.00	2.00
* 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: Developed by the authors

Therefore, as seen on 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, Frenix should produce 100 units of product P, and the remaining time should be used to manufacture product T, in the light of the constraint observed in sector "b". Chart 8 shows the highest profit that can be obtained initially.

PRODUCT ***P***		
Market		100 units/week
Contribution Margin	R$	45.00 (90 - 45)
Total time used in "b"		1,500 minutes
Amount of time remaining in "b" (for **P)**		900 minutes
Gross Profit with P (45 units x R$ 100)	R$	**4,500.00**
PRODUCT ***T***		
Market		50 units/week
Contribution Margin	R$	60.00 (100-40)
Capacity in function of "b" (900/30)		30 units/week
Gross Profit with T (30 units x R$60)	R$	**1,800.00**
Total Gross Profit (P + T)	R$	6,300.00
Operating Expense	R$	(6,000.00)
Net profit / week	**R$**	**300.00**

Chart 8 - Calculation of highest profit using TOC
Source: Developed by the authors

According to Chart 8, the best profit that can be obtained is the one shown, i.e., R$ 300.00 a week. This results from the comparison of the two alternatives assessed in terms of weekly profit maximization, as on Charts 7 and 8, which, according to the conventional approach, (Chart 7) showed a R$ 300.00 loss and, with the adoption of the TOC approach (Chart 8) showed a **R$ 300.00** 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 CONSIDERATIONS

As has been shown, TOC acts preventively and effectively, by controlling the effects and eliminating the causes of constraints, without affecting the flow, by using existing capacity to supply 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.

TOC is especially useful in 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 at Frenix, 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%. It 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 TOC, one should bear in mind that the case study mentioned 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 lot of similarity with other small manufacturers in Brazil.

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 problems that may jeopardize the performance of these bottleneck resources, which in turn jeopardizes the operating result of the business as a whole.

TOC principles offer new insights into old problems. This furthers a better understanding of these problems and encourages a search for new solutions. The Socratic Method used makes the idea **belong** to whoever is going to put it into practice rather than to whoever idealized the change. The important thing 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 difference.

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

In addition, other possible surveys could aim to analyze the elements portrayed here in greater depth, exploring these issues in detail, to analyze how operating elements are combined in the context of small firm management, as well as the way in which these elements support their competitive strategies based on the use of TOC.

REFERENCES

ANDERSON, D. **Agile management for software engineering:** applying the theory of constraints for business result. New York, Prentice Hall, 2006.

BLACK, J. T. **The design of the factory with a future.** New York: McGraw Hill, 1991.

DETTMER, H. W. **The logical thinking process**: a systems approach to complex problem solving. Milwaukee: Quality Press, 2007.

DRUCKER, P. F. Management and the world's work. **Harvard Business Review,** Boston, v. 66, n. 5, p. 75-76, Sept./Oct. 1988.

FREITAS, M. E. Cultura organizacional: grandes temas em debate. **Revista de Administração de Empresas,** São Paulo, v. 31, n. 3, p. 73-82, jul/set. 1991.

GOLDRATT, E. M. **Production the TOC way with simulator.** New York: North River Press, 2003.

GOLDRATT, E. M. The theory of constraints and its thinking processes: a brief introduction to TOC. Connecticut: Goldratt Institute, 2007.

GOLDRATT, E. M.; COX, J. Hierarchical management - the inherent conflict**. The Theory of Constraints Journal**, New Haven, v. 1, n. 1, Oct/Nov. 1987.

GOLDRATT, E. M.; COX, J. **Manual da teoria das restrições.** Porto Alegre: Bookman, 2002.

GOLDRATT, E. M.; COX, J. The fundamental measurements. **The Theory of Constraints Journal,** New Haven, v. 1, n. 3, p. 1-21, Aug/Sept. 1988.

GOLDRATT, E. M.; COX, J. **The goal.** New York: North River Press, 2002.

GOLDRATT, E. M.; COX, J. The importance of a system's constraints. **The Theory of Constraints Journal**, New Haven, v. 1, n. 4, Feb/Mar. 1989.

RICKETTS, J. A. **Reaching the goal:** how managers improve a services business using goldratt's theory of constraints. New York: Pearson Education, 2007.

PLUTE, M. **Tool management strategies**. Cincinnati: Hanser Gardner, 1998.

SHINGO, S. **Le systeme SMED:** une révolution en gestion de production. Paris: Les Éditions d’Organisation, 1987.

SLACK, N. **Administração da produção**. São Paulo: Atlas, 2002.

STANDARD, C.; DAVIS, D. **Running today’s factory:** a proven strategy for lean manufacturing. Cincinnati: Hanser Gardner, 1999.

TOONEY, J. W. **MRPII planning for manufacturing excellence.** NewYork: Champman & Hall, 1996.

TUBINO, D. F. **Sistemas de produção:** a produtividade no chão de fábrica. Porto Alegre: Bookman, 2005.

WOOLDRIGE, M.; JENNINGS, N. R. Intelligents agents: theory and practice. **The Knowledge Engineering Review,** NewYork, v. 10, p.115-152, 1995.

A TEORIA DAS RESTRIÇÕES EM UMA EMPRESA DE PEQUENO PORTE: UMA ESTRATÉGIA ALTERNATIVA PARA A GESTÃO DE FABRICAÇÃO.

Resumo

O objetivo deste artigo é estudar a aplicação prática da Teoria das Restrições (TOC) e identificar algumas das principais estratégias relacionadas à sua utilização. Pretende-se provar que essa teoria não trata as organizações como uma coleção de processos independentes, mas sim como um sistema integrado. Sob essa teoria, a organização é vista como uma cadeia sincronizada, em que as relações entre cada atividade forma um sistema completo que é capaz de criar uma sinergia para a empresa inteira. O TOC mostra que cada sistema está sujeito a pelo menos uma restrição que não o deixa alcançar altos níveis de desempenho. Um estudo do uso da TOC em uma empresa de pequeno porte mostra os resultados obtidos por sua aplicação. Sua utilização possibilita identificar a restrições e, assim, melhorar o desempenho da empresa e de sua produtividade.

Palavras-chave: Teoria das restrições, diferenciais estratégicos, produtividade, fabricação, pequena empresa.

Data do recebimento do artigo: 20/07/2009

Data do aceite de publicação: 15/10/2009