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**THE THEORY OF CONSTRAINTS AS A BASIS FOR PRODUCTION
PROCESS IMPROVEMENT MODEL**

All that limits the achievement of the company's goal, organizational unit's goal or the process's goal represent the problem. Achieving goals assumes certain resources and capabilities. If a company does not have necessary resources and capabilities in sufficient amount or of an adequate quality, a problem may appear, which is referred to as limitation. Limitations of a company, primarily as the production system, are the subject of the theory of constraints. The theory emphasizes the need for identification of the constraints and their elimination in order to achieve a defined goal. For this purpose, the creator of this theory, Goldratt, suggests the usage of 3 criteria, namely: throughput, inventory and operation costs. In addition, it is necessary to find such a combination of resources that provides the best relationship between these measures. This involves finding the best way of resources usage and processes optimization and this can be achieved by applying certain mathematical models. This paper presents the role and significance of the theory of constraint' for improving the efficiency of production process, which is based on eliminating bottlenecks, as limitations of increasing the efficiency of processes, and consequently profits.

Keywords: theory of constraints, production process, efficiency, resources.

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**ТЕОРИЯ ОБМЕЖЕНЬ ЯК ОСНОВА МОДЕЛІ ВДОСКОНАЛЕННЯ
ВИРОБНИЧИХ ПРОЦЕСІВ**

У статті розглянуто обмеження при досягненні мети компанії, цілі її організаційної одиниці або мети процесу. Досягнення мети передбачає певні ресурси і можливості. Якщо компанія не володіє необхідними ресурсами і можливостями в достатній кількості і відповідній якості, може виникнути обмеження. Вони є предметом теорії обмежень, яка підкреслює необхідність їх ідентифікації та усунення для досягнення певної мети. Для цього автор теорії обмежень, Голдратт, припускає використання 3 критеріїв: пропускна спроможність, інвентаризація та експлуатаційні витрати. Визначено роль і значення теорії обмежень для підвищення ефективності процесу виробництва, яке засновано на усунення "вузьких місць" як обмежень підвищення ефективності процесу і, отже, прибутку.

Ключові слова: теорія обмежень, виробничий процес, ефективність, ресурси.

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**ТЕОРИЯ ОГРАНИЧЕНИЙ КАК ОСНОВА МОДЕЛИ
СОВЕРШЕНСТВОВАНИЯ ПРОИЗВОДСТВЕННЫХ ПРОЦЕССОВ**

В статье рассмотрены ограничения при достижении цели компании, цели ее организационной единицы или цели процесса. Достижение цели предполагает определенные ресурсы и возможности. Если компания не обладает необходимыми ресурсами и возможностями в достаточном количестве и соответствующего качества, может возникнуть ограничение. Они являются предметом теории ограничений, которая подчеркивает необходимость их идентификации и устранения для достижения определенной цели. Автор данной теории, Голдратт, предполагает использование 3 критериев, а именно: пропускная способность, инвентаризация и эксплуатационные

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расходы. Определена роль и значение теории ограничений для повышения эффективности процесса производства, которое основано на устранение "узких мест" как ограничений повышения эффективности процесса и, следовательно, прибыли.

Ключевые слова: теория ограничений, производственный процесс, эффективность, ресурсы.

Introduction. The development of industry and the consumer society has led the competition at the global market to unimagined proportions. Companies are operating at the global market, in an environment characterized by constant presence of often unpredictable changes. The pressure from competitors and consumers has been increasing and therefore companies invest extraordinary effort to accelerate the production and delivery of products, to improve production program and provide variety of products, as well as to improve product quality with parallel reduction of production costs. Also, the market is constantly sending signals related to the introduction of innovations (new and improved products and processes) and new sources of ideas for improving business.

The importance of factors affecting competitiveness has been changing during the time. In the past, competition was based on the efficient usage of limited financial resources. Today it is based on intangible resources, which provide unlimited potential for companies' growth. This does not mean that the efficiency of resource usage is not important, or that costs and time are not important factors of competitiveness. On the contrary, the efficiency is important, but beside cost and time considerable factors of competitiveness are quality and flexibility in terms of improving offered value for consumers (Chase et al., 2006). Identification of key competencies is very important, but equally important is their constant review. This review is supposed to prevent the key competence from turning into the key rigidity.

Therefore, companies must find way to encourage employees to be engaged in the process of formulating and implementing strategy and continual improvement of operations. In this sense, traditional, cost-driven economy based on natural resources has to transform into the economy based on knowledge and information, or the economy driven by quality. Changes that occur in the company environment reflect the models and concepts of management. In this regard, in response to modern business conditions, managers have to promote and implement new methods and concepts of management. The great number of methods and concepts deals with operations management, since the practice of successful companies has shown that the greatest savings may be provided at the bottom-line. One of the most popular tools among operations engineers for providing operations results in terms of time, quality and costs is the theory of constraints.

The theory of constraints – basic ideas. The significant number of problems that managers encounter nowadays relate to high inventory level, high labour costs, insufficient increase in sales, which consequently leads to reduction of amount of money that companies have at their disposal. According to Goldratt, the main reason for these consequences is the lack of understanding of the concept and the essence of productivity. Goldratt defines productivity as an action that helps company reach its goal, and therefore any action which does not contribute to company's approaching its goal may be observed as unproductive (Hsu, Sun, 2005). The only goal of any com-

pany, no matter what its managers claim, is generating money, and in this sense it can be said that all actions that contribute to generating money are productive, or that all actions that do not contribute to money generation are not productive.

The theory of constraints is based on 2 main principles. The first relates to production limitations and provides adequate management of constraints, usually marked as bottlenecks, the resources which limit production, and is known as Drum-Buffer-Rope principle. The second principle relates to the troubleshooting and the analysis of symptoms and discovering the root causes of problems (Gardiner et al., 1993) and represents the thinking process. The first one is the inseparable part of daily process improvement or continual improvement. The second one is the inseparable part of radical process improvement of process restructuring and is applied when incremental, continual improvements no longer make difference and increase efficiency, or when there is a problem with ineffectiveness.

From numerous conversations he had with successful and unsuccessful managers, Goldratt recognized that the ones that belong to the second group do not really know what the goal of their business is (Goldratt, Cox, 1993). Specifically, these managers reported very different business goals, such as increasing efficiency, increasing market share, increasing product quality, improving technology, increasing sales volume and so on. Few managers said that the goal of their business is increasing productivity. However, according to Goldratt, increasing productivity is not the goal of company, but the "art of approaching of a company to its goal" (Alukal, Manos, 2006). Thus, measurement of productivity does not make sense if the goal is not clearly defined.

Goldratt did not contest that business efficiency should be increased, technology improved, product quality increased, as well as sales volume, market share and so on (Kaufman, Sato, 2005). However, all the mentioned he has not observed as goals of a company, but as means or tasks that a company should perform in order to achieve its primary goal. If one accepts Goldratt's view, it can be said that monistic theory on objectives is acceptable today, with one difference that as the only goal is not promoted as profit maximization, but generating enough money for satisfaction of all stakeholders' needs (Atkinson, Epstein, 2000). It should be noted that the achievement of a defined objective will provide achievement of the objectives of all stakeholders or will lead to the achievement sub-goals of a company.

In principle, the limitation can be external or internal. For example, when a company cannot sell the products that are produced one can say that it is due to the external or market constraint. External constraint occurs in case when a company is unable to procure inputs to the extent that it needs for production enough to meet demand (Völberda, 1999). If demand exceeds possibilities of a company, in terms of production and sales volume, the limitation is internal or, it can be said, it is resource constraint (Baxendale, Raju, 2004). The resource that has the lowest capacity leads to appearance of variations in process and restricts the whole system or the process.

In the first case, when limitation is demand, the flow of production should be aligned precisely with the demand. In the second case, when limitation is one of the resources, the production flow should be aligned with the capacity of the specific resource (limitation). In any case, the production flow is determined by the rate which imposes a limitation, either internal, or external. For this reason, it is neces-

sary to focus precisely on the resource that represents the limit or that is a critical resource (Balderstone, Keef, 1999).

Measures and principles of the theory of constraints. The data provided by accounting, through accounting reports, refer to a company as a whole and for a pass time. However, managers need reports and measures that would allow monitoring of a company on a daily basis and for the parts of a company, e.g. for certain organizational units, for certain processes, certain operations etc. In this sense, Goldratt suggests the use of the following operations measures:

- Throughput – a company generates money through sales, not production, because if something is produced, and cannot be sold it does not contribute to generation of money;

- Inventory – the money "trapped" in the company or all the money the company invested for the purchase of resources, which have to be transformed into products (in this case, inventory also includes money invested in equipment that has not yet been fully amortized, or current, non-depreciation value of equipment);

- Operating expenses – the money that the company spends to transform inventory into "throughput".

When in the company throughput increases while inventory and operating costs have been reducing, this means that it is on the track to achieve its goal, formulated as generating money. In order to make this possible it is necessary to apply the process approach to management and balance the manufacturing process with related business processes (Kaufman, Sato, 2005).

In this regard, increasing processes' efficiency represents the sub-goal of the company, which, among the others, has to provide the achievement of the primary objective. Increasing the efficiency of processes is important for providing balanced process flow (Freeman, 2001).

The connection between capacity of the company's processes and demand has to be identified (Dowdle et al., 2003). However, the company does not need to balance process capacity with demand, but the flow of work in process with demand, or, in other words, it is necessary to balance the flow, and not the processes' capacity. This approach questions a long valid assumptions and ideas about capacity and demand compliance. This is because the complete balancing of capacity does not always have the desired effect.

Such compliance would be possible only if the processing time at all stages of the process is continuous, or if there are no variations. Variations in processing time, or changes in processing length, cause unused capacity at the following stages of the process or the following resources on one side, and accumulation of work in process, on the other (Fahy, 2002). In this way, the resources, which according to the size of the capacity do not represent bottleneck, due to the variations in processing time can get the epithet "bottleneck". For this reason managers should not balance the capacity of resources, but the process flow.

This one and the other 9 principles of Goldratt's theory of constraints may be summarized in the following way (Anderson, 2004):

1. It is necessary to balance the flow, and not the capacity;
2. Utilization of the bottleneck is determined by some other restrictions in the process, not its capacity;
3. Utilization and resource use are different concepts;

4. An hour lost at the resource that represents the bottleneck is an hour lost the whole process;
5. An hour saved at the bottleneck is a mirage or an illusion;
6. The series of transfer need not and should not be equal to the size of production series;
7. The bottleneck controls or regulates the throughput and inventory in the process;
8. The size of the production series need not be fixed;
9. The lead time is the result of the process design;
10. When designing the process one should always bear in mind the constraints (bottlenecks).

When someone observes the principles of the theory of constraints he may conclude there is no natural border between incremental improvements and process restructuring. Although authors usually speak with "either/or", these two types of innovations are actually mutually connected or it may be said that they lean on each other.

Process orientation – the base for elimination of the constraints. The concept of process orientation is not new. Observation of related activities as a series of activities and the creation of flow is present in economic theory over 300 years. One of the first authors who in his works spoke of the process (analyzing the production of the pin factory in England) was Adam Smith. However, the process approach gains importance in recent decades (Gross et al., 2003), because it represents the relevant response to the challenges which the companies should respond. Process orientation is based on communication, decentralization, coordination and teamwork.

The dynamism of the environment and the need for flexibility caused the adjustment of organizational structure, by adopting a process orientation. Besides that, transfer from functional to process orientation is primarily a consequence of the need for continuous analysis and improvement of business processes, continuous surveys of customers' satisfaction and relations, and aspiration to establish an effective cost control. In this way company increases its flexibility. This also leads to the transformation of the role of managers and employees. The role of managers is evolving from the dominant control function into impact (influence) function. On the other hand, employees become members of the team whose main task is to contribute to creation of value for customers (Keyte, Locher, 2004). They are no longer just manual, physical asset, but the so-called thinking capital, which may significantly increase company's competitiveness and improve market position.

Process orientation is not just about cooperation between the functions of a company. It also means cooperation and communication between superior and their subordinates, thus allowing the full inclusion of all employees in the implementation of strategy and process improvement. Two-way flow of suggestions, guidelines and reports about the work appears as a consequence of changes in the relationship between managers and employees, but also as a result of changes in the relationship between employees and company performance. Specifically, nowadays at successful companies a tendency can be observed that managers give their employees (subordinates) more authority, especially when it comes to choosing the method of implementing tasks entrusted to them. Thus, managers view employees as team members,

with which they exchange information in the form of suggestions and report on work, not only as subordinates who will accept suggestions and orders, and in return provide the reports (Alukal, Manos, 2006). This assumes that employees must have multifunctional training and wide spectre of knowledge and skills.

Process orientation provides many benefits for companies. They are reflected in the following:

- Identification of the "process owner", responsible for the process from beginning till the end, avoiding traditional fragmentation of responsibility between managers of different organizational units,
- Focus on the process of ensuring the realization of customer demands, assuming that each process has a user,
- Through defining process borders, and customer and supplier of processes, better communication and better understanding of the requirements is achieved,
- Lower costs and shorter time of process implementation,
- Reduction of the sub-optimization risk because one man manages the entire process (which runs through several organizational units), rather than individual organizational units,
- For each process key performance indicators may be identified, and at this monitoring provides a continuous process improvement.

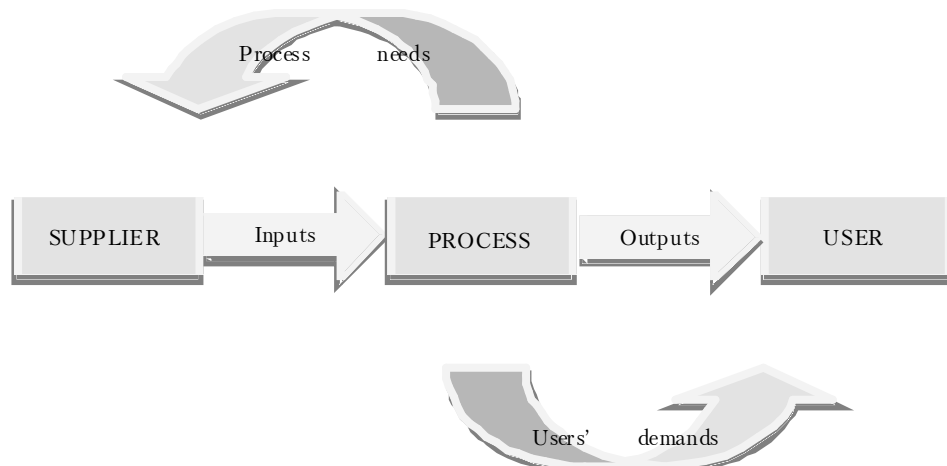


Figure 1. **Process approach** (Andjelkovic, Pesic, 2010)

The most significant characteristic of process orientation and the most important principle is identification of the owner of the process, because it helps overcoming the greatest limitation of classical organization – the question of competence and responsibility (Frishammar, 2003). However, process orientation does not mean completely abandoning the traditional hierarchical structure. Company may still retain functional division of work, but the realization of the activities and tasks should be based on cross-functional teams and cooperation.

Process orientation assumes that company's entire business is seen as a complex process, which task is to respond to consumers' demands, to provide maximum added value and to contribute to the achievement of the primary goal – generation of

money. At the same time, it increases reliability and responsiveness to changes in the environment. Business management is provided through process control, which assumes continuous monitoring (Harrison, Pelletier, 2000). This means that process performances are continually measured and analyzed, and on that basis continually improved. These measurements usually assume observation during certain period of time, when actually time series have to be analyzed. Time series may be approximated through polynomials of n -th degree (Dasic, 2011; Dasic, 2012). In this way, managers may predict certain problems and variations in process realization and take some actions in order to prevent their appearance and provide process stability.

Constraints of efficient realization of business processes. Achievement of the overall objective is conditioned by synchronization of business processes (Laguna, Marklund, 2005), especially through providing synchronization of manufacturing processes. As it is already mentioned, synchronized manufacturing or synchronized manufacturing processes do not involve balancing of capacities, but of the process flow. This interpretation questions a long valid principle, which assumes the necessity of adjusting capacities in order to eliminate bottlenecks (Hsu, Sun, 2005). The balance of capacities of all resources would be required and desirable only when a process would not be characterized by variations. However, given that the variations are inherent to any process increase in processing time on one resource, would cause the appearance of bottleneck and piling of work in progress, on the one side, and unused capacity, on the other.

To reduce the influence of variations there are two solutions. First assumes the increase of work in progress, and is not good, because the goal of a company is to increase throughput while reducing inventory (including inventory of work in process) and operating costs. The second assumes actions through which capacity of machines or any other resources, which represents the bottleneck, or in front of which there are inventory of work in process, can be increased (Fahy, 2002).

Analysis of bottleneck, as the limiting factor, is desirable to connect with determination of the size of a production batch. As it is known, production time consists of preparation and processing time. Time for preparation of a machine often assumes a significant amount of production time, so it is desirable to shorten it in favour of processing time. This can be provided exactly by increasing the size of a batch. However, one should take into account that the size of a batch may not be equal to the size of transfer series. This means that it is not necessary to finish one operation for the whole production series in order perform other operations. On the contrary, as early as it is possible after first operation at the certain part of the batch, the treatment of batch on the other machine can start (Volberda, 1999). In this way, process time will be reduced, as well as the work in progress, through the reduction of transfer series' size. When thinking this way, one can ask what will happen with the costs of process realization due to frequent moves from machine to machine or from resource to resource (because series of transfer are smaller). However, bearing in mind that other machines, except the one that represents the bottleneck, have unused capacity, and that employees who are responsible for their supervision or management have some free time, one can assume that costs of transport of work in progress will not actually increase, because employees can take this spare time for providing internal transport.

According to some authors (Trietsch, 2005), the basic principle of the theory of constraints, which refers to the connection between the bottleneck or limitation and the resources that precede it (it is the DBR principle) is superfluous, and for the sake of theory of constraints improvement it should be eliminated. Therefore, management by constraints represents the difference between principles formulated by Goldratt and the principle of Drum-Buffer-Rope. These authors suggested that management by constraints should be implemented through 6 steps (principles). The first step is referred to as 0, because the cyclic repetition does not relate to it. These are the following steps:

0. Choose a process that should be improved and specify how to measure the success of implementation of the improvements,

1. Identify the constraint of the process that is subject to improvement;
2. Manage the constraint to ensure maximum convergence towards improvement objective;
3. Subordinate everything else to identified constraint;
4. Improve the constraint in a way that assumes increased capacity of the resource that represents the constraint;
5. Repeat the steps from 1 to 5, because after step 4 new bottlenecks may arise.

Complete balance of capacities means full utilization of capacities' of all resources (machines). Bearing in mind that this is almost impossible, such balance can be called "naïve balance". More probable scenario assumes balance that can be called "simple balance", which means there is balanced utilization of the resources' capacities (utilization of capacities is equal), but where capacities utilization is below 100% capacity. The "simple balance" is more realistic as compared to the "naïve balance". However, the optimal scenario for a company is the "economic balance". Economic balance exists in the case of maximization of throughput, which means balanced capacities of resources, below 100% if utilization, but due to market demand (Trietsch, 2005). In this way, capacities of resources are utilized maximally, but there is not unnecessary production which will provoke increased inventory (and if inventory is not turned into throughput there is no use of fully utilized capacity).

Conclusion. Today, when numerous products of many foreign companies are present in Serbia, domestic companies must direct their attention to competitiveness, in order to overcome burden of transition. However, this effort for most companies in Serbia usually relates to cost reduction. Namely, theory and practice shows striving for reduction of costs per unit, with the comment that cost reductions lead to higher profits. But in modern conditions, the focus must not be on cost, but on created value. If a company, in order to reduce costs per unit, focuses on increasing production volume, without taking into account the needs of consumers, throughput and resource constraints, it will face the adverse effect, precisely the increase of costs, which will jeopardize the ultimate goal, which is money generation.

Otherwise, when a company takes care of throughput and resource constraints in the structuring of production, although the primary intention is not cost reduction, it will emerge as one of the desired effects. This paper presents a method that allows maximum exploitation of limiting resources, which is consistent with Goldratt's suggestion that every moment lost at the resource that represents the constraint is lost forever for the entire company and, more importantly, it represents the lost chance for increasing profit or generating money, which is the primary goal of any company.

If the increase in production volume in order to provide lower costs per unit is followed by non-balanced work of mutually connected organizational units (departments) or facilities, inventories of work in progress will be at even higher level. This occurs as a result of optimization on the departmental basis and not at the process level. In this case each department or plant increases production volume, regardless whether that amount is needed by the next department in the chain. This behaviour leads to increased efficiency of the department, but only fictitious, given the existence of an extremely high level of inventory. Instead of optimization on the departmental basis, it is necessary to optimize the process, whose activities are usually carried out in several departments. If process approach is applied in a company, it may be seen which department or facility is the weakest link in the value chain, i.e. represents some kind of constraint. Thus, making good decisions involves getting to know the constraints or limitations, the most important operational measures and the possible ways for elimination of bottlenecks, as restrictions.

To achieve the goal of a company, managers must take care of daily operations or analyze on the daily basis what is happening in the company. For this purpose, Goldratt suggests 3 basic criteria, throughput, inventory and operational costs. These measures are used for constantly searching for a new bottleneck and unused capacity, to ensure harmonization of the work flow through the entire company.

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