

## PRODUCTION ECONOMICS WITH THE USE OF THEORY OF CONSTRAINTS

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**Abstract** The article is a literature review in the scope of theory of constraints in manufacturing companies developed by E. Goldratt. Particular emphasis is placed on the economic sphere of such companies as opposed to the literature dedicated to solving production control problem by using DBR technique advocated by developers and active users of theory of constraints. The article aims to show the approach to the presentation of measurements developed by theory of constraints in the context of corporate net profit and return on invested money in productive activities in the real industrial plants. This is called throughput accounting that indicates the effectiveness of money processing in the production system. In addition, literature analysis aims to show the degree of utilization of theory of constraints in scientific environments in the context of efficiency measures in achieving the goal objective of making money or achieving degree of operational expenses savings in production systems.

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## 1. INTRODUCTION

Managing manufacturing plant is a continuous process of decision-making. A good manager is a manager who can make the right decisions bringing tangible economic benefits of the company as a whole. Accuracy of a decision depends largely on accepted economic standards to justify their making. This of course is a truism, but from the point of view of the application of accounting techniques is no longer so obvious. Taking the example of a basic calculator of own production cost the level of complexity and difficulty in technical cost-sharing justification for the actions taken in the production process result in many problems when making business decisions solely on its basis (Kaplan & Cooper, 1998). Therefore, more attention is given to innovative analytical approaches which include throughput accounting developed by E. Goldratt, an originator of Theory of Constraints.

Theory of Constraints (TOC) has become a common tool to support decisions made by production manager every day. Its ease of assimilation and absolutely common sense approach to solving problems of an organizational nature aimed at achieving improvement in net profit and return of investment has contributed to the competitiveness of many companies and international corporations. Simplicity of TOC combined with the developed procedures of ongoing improvement of companies constraints gives results almost immediately, making it the science taught in many technical and economical universities in the world (Koliński & Tomkowiak, 2010).

E. Goldratt developed the methods that solve the economic problems of enterprises mainly based on the methods applied in physical science. His work in this area has taken in the late 1970s in response to the request of chicken coop manufacturer who placed in Israel (Bylinski, 1983). For developed management methods he formulated the general guidelines of using them for which he coined the name of Theory of Constraints. TOC was described in many books, which have taken the form of an incredible business novels (Goldratt & Cox, 1984), (Goldratt & Fox, 1986), (Goldratt, 1994). Despite a fairly clear message that Goldratt developed by his literature as to the perception of the key issues associated with the approach to economic management of manufacturing companies it can be noticed a preponderance of the literature related exclusively to the production scheduling issues (Kosieradzka & Skorupa, 2006). Technique developed by him and called DBR (Drum-Buffer-Rope) used for scheduling and production control has devoted much space in research reported in the literature. This article is therefore a complement of the missing Goldratt's premise who claimed that traditional cost accounting should be regarded as a product of a bygone era. Instead, he proposed a novel throughput accounting, whose fundamental importance is presented in the book of his close collaborator (Corbett, 1998).

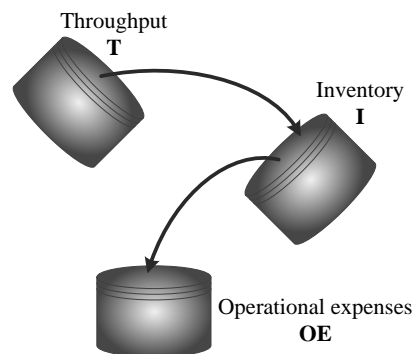
This publication provides an overview of the literature describing the study on the usefulness of throughput accounting as applied to manufacturing companies at a general level. Therefore, an essential part of this paper is devoted to description

of works using throughput accounting in different case studies. This description is based on three years of research devoted to the analysis of literature in the field of theory of constraints by the author. Conclusions and directions for further work are presented in the summary.

## 2. THEORY OF CONSTRAINTS AS A TOOL OF DECISION-MAKING PRODUCT-MIX OPTIMIZATION

The main message of Goldratt's idea was a new look at the financial issues related to the execution of production processes. According to Goldratt, the most important duty performed by production manager is to provide manufacturing control so as to achieve the primary objective of the company which is making money. The key has become to establish the main production factors presenting the results of the execution of production processes in monetary units. Thus, Goldratt developed three basic measures and four relative and absolute indicators showing whether manufacturing company is moving towards achieving the goal (Lockamy & Spencer, 1998).

The three basic production measures are interrelated. These are: **throughput  $T$**  in other words money that enter the production system, **inventory  $I$**  in other words money that are locked up inside the production system and **operational expenses  $OE$**  in other words money that leave the production system (operational expenses contribute towards changing inventory into throughput). According to Goldratt, the most important of these three measures is throughput because it is directly related to the sale of finished products. Throughput is calculated as sales less the total variable costs which include the cost of materials used, transport costs, commissions, discounts, etc. These three basic measurement can be represented graphically as in Fig. 1.



**Fig. 1** Three basic measures of Theory of Constraints

Fig. 1 shows that the objective of making money can only be achieved if the throughput is greater than the other two measures of Theory of Constraints. There-

fore, all decisions made by production manager should be directed in the first instance for enlarging throughput with the control of two other measures (inventory and operating expenses). Hence, the definition of throughput accounting directed towards this implication are commonly used by adherents of the Theory of Constraints. It is also seen a big difference compared to the cost accounting that assumes to reduce production costs as a key element in the competitiveness of enterprises.

In order to more clearly illustrate the interrelationships between the three main measures of throughput accounting Goldratt developed four indicators based on the traditional definition of financial indicators such as net profit or return on investment. Throughput accounting recognizes these indicators in a modified form. Thus, the **net profit**  $NP$  is calculated as the difference between throughput and operational expenses:

$$NP = T - OE \quad (1)$$

Net profit  $NP$  becomes the basis for calculating **return of investment**  $ROI$ , which is the indicator showing the pace of how fast a company makes money. It contains all the basic measures of Theory of Constraints. Return on investment  $ROI$  is calculated as follows:

$$ROI = \frac{NP}{I} \quad (2)$$

The third indicator of throughput accounting is the productivity ratio  $P$  calculated from the relationship:

$$P = \frac{T}{OE} \quad (3)$$

The last indicator of throughput accounting is the inventory turns  $IT$  calculated from the relationship:

$$IT = \frac{T}{I} \quad (4)$$

Throughput accounting was developed on the assumption of occurrence of at least one constraint in the production system. Goldratt has defined two types of constraints, i.e. external constraints connected with the ambient market and lack of demand for company products and internal constraints related to the lack of production capacities required for the production of ordered products. In the case of external constraints, the emphasis is on the use of an aggressive marketing campaign, using innovative and seminal ways of acquiring new customers or designing and developing new products by analysing the critical chain (Goldratt, 1997). In contrast, the occurrence of internal constraint being a bottleneck (i.e. at least one overloaded work station) gives rise to application of throughput accounting by production manager in order to decide on the choice of product mix being produced on a bottleneck. This is a typical optimization problem wherein according to throughput accounting achieving the highest

return on investment is assumed as an optimization criterion in certain period of time and at a given level of orders.

The presented approach to the calculation of the key economic indicators of manufacturing enterprises has been deemed as a mental leap in the domain of operations management (Watson, Blackstone & Gardiner, 2007). So far, applied and rapidly developed techniques of cost accounting have been overthrown and replaced by a modern approach proposed by TOC (Geri & Ronen, 2005). Finally, TOC has also been accepted by the academic community through its recognition as a theory meets the quality requirements according to the Wacker's model (Wacker, 2008), (Naor, Bernardes & Coman, 2013).

It should be also mentioned that the TOC is associated primarily due to production scheduling using the DBR technique which is the development of Goldratt's implementation program known as OPT – Optimized Production Technology (Spencer & Cox, 1995), (Crocchi & Pozzetti, 2000). DBR technique constitutes a development of methods based on optimization of the production schedule. The optimization criterion in this case is not to minimize the makespan but reduce the level of inventories and shortening lead time (Ye & Han, 2008), (Gonzales, Framinan & Ruiz-Usano, 2010). According to the first principle of OPT implementation a production manager should not seek to balance the workload of machines but to balance the flow of jobs in a production system. It makes DBR technique alike in terms of objectives used to other modern production management techniques. Hence, a lot of attention in the literature is devoted to the comparison or combining DBR technique with two other techniques, which include JIT - Just in Time and MRP - Materials Requirements Planning (Steele, Philipoom, Malhotra & Fry, 2005), (Watson & Patti, 2008), (Cyplik, Hadaś & Domański, 2009), (Hadaś & Karaśkiewicz, 2014), (Darlington, Francis, Found & Thomas, 2015). In addition, many TOC proponents perceive the possibility of a combination of MRP techniques and DBR to create a new generation of ERP systems focused on constraints management of manufacturing enterprises (Miltenburg, 1997), (Gupta & Snyder, 2009), (Golmohammadi, 2015).

DBR technique has been developed for meeting the basic assumptions of the theory of constraints which is to improve production processes in order to increase throughput and reduce inventories and operating expenses. In order to improve production processes developed heuristic consists of five major steps that must be carried out in order to ensure the achievement of the quoted goal. The heuristic was called the process of ongoing improvement (POOGI), which include (Goldratt & Cox, 1984):

- Identifying of the system's constraint(s).
- Deciding how to exploit the system's constraint(s).
- Subordinating everything else to the above decision.
- Elevating the system's constraint(s).
- After breaking constraint(s) in the previous steps, returning to step one and not allowing inertia to cause a system's constraint.

The constraint(s) of the production system constitutes central attention of theory of constraints. Production schedule is created in relation to processing capacity

of constraints. If, for example production system has one constraint in the form of a machine (in this case a machine is not able to process all jobs within a specified period of time), then a production manager has to decide which jobs will be processed on the constraint. According to the theory of constraints the choice can be undertaken based on underpinnings that jobs should be processed in accordance with decreasing workload level utilization of the constraint calculated from the relationship:

$$CCR_i = \frac{T_i}{t_i} \quad (5)$$

In the above formula, the **workload level utilization**  $CCR_i$  of the constraint per processing of one production unit  $i$  (one job or one product) is obtained by dividing throughput  $T_i$  derived from the sale of one production unit by the time  $t_i$  spent on processing of one production unit.

The POOGI heuristics met with harsh criticism from academic community. The main reason of academic scepticism is the manner of products/jobs selection targeted to the constraint(s) utilization which does not give the optimal solution associated with maximizing net profit and return of investment in the long-term period (Ifandoudas & Gurd, 2010), (Souza, Sobreiro, Nagano & Manfrinato, 2013). In addition, the theory of constraints does not disclose the relationship between the operating activities of the production company and the valuation of products, although the price of each product is one of the key parameters for throughput calculation  $T_i$ . Furthermore, proposed by Goldratt POOGI heuristic gives the adverse consequences if there are many constraints in the production system which has been proven in several publications (Bhattacharya & Vasant, 2007), (Linhares, 2009), (Rajesh, 2014). Similarly, it is demonstrated a number of cases indicating weakness of POOGI heuristic compared to traditional methods of product mix selection based on linear programming (Souren, Ahn & Schmitz, 2005). These are special cases what the authors emphasize in their conclusions. These shortcomings cannot capture the power of the theory of constraints, but rather are premises for further development.

Throughput accounting is used to select products that should be processed by the constraint in a given period of time. This problem is known in the literature as production mix problem usually identified with the name of the PQ problem. PQ problem was first described by the Goldratt (Goldratt, 1990). PQ problem consists of a simple example in which production system produces two products P and Q on four successive machines A, B, C and D (manufacturing process consists of four stages). Some input parameters are known and invariable such as sales prices of products, purchase prices of raw materials, demand per products in a given period of time, cycle times or unit processing times for products manufactured on each machine and the total available time on machines in a given period of time. Data for this example (in particular, unit processing times) are established in such a way that one of the machines is overloaded in a given period of time (there

is always at least one machine/constraint incapable of producing all the products P and Q as results from demand). The problem is to decide on the number of products P and Q directed to the production in order not to exceed the total available time and to maximize the profit of the company (Souza et al., 2013). With the development of the theory of constraints PQ issue has evolved. Currently in the literature more complex forms of this example involving a larger number of products, machines and more parameters, even such as overheads and investment components are examined (Golmohammadi & Mansouri, 2015).

Literature divides PQ problem solutions into three categories. The first category of solutions contains all the greedy algorithms mainly used to solve small-scale problem instances because of the long computation time required to find the optimal solution (Balakrishnan & Cheng, 2000). The second category of solutions is based on POOGI by creating new heuristics used mainly to solve PQ problem with the occurrence of multiple constraints within the production system (Sobreiro & Nagan, 2012, Badri, Ghazanfari & Shahanaghi, 2014). The last category of solutions is the group of metaheuristics solutions looking for suboptimal solutions to solve large-scale problem instances (Chaharsoogi & Jafari, 2007), (Wang, Sun, Si & Yang, 2009). The analysis of the literature exhibits the development of heuristic and metaheuristic methods to solve production mix problem is continually growing.

### 3. CONCLUSION

This article showed a new face of accounting developed based on years of practical work of E. Goldratt in the field of operations management. Whereas two main areas of accounting that are financial accounting as a part of the reporting for internal and external accounting and management accounting as a part of preparatory for supporting planning decisions E. Goldratt decided to revolutionize the second part claiming that the existing tools of cost accounting are outdated and they provide false information on the basis of which a production manager has to take key business decisions. The newly developed throughput accounting is likely to replace used cost accounting as evidenced by the outcome of environmental surveys aimed at changing the paradigm of management accounting conducted in Polish researchers community (Engelhardt, 2005).

The strength of the new approach to the management accounting can also be seen in the fact that in 2004 the Financial Accounting Standards Board (FASB) for the first time in 50 years changed the method of accounting for inventory in companies postulated the indication of inventory value on the basis of throughput accounting. The new model of inventory accounting has been implemented in many industries and is used today successfully (Śliwaczyński & Koliński, 2012).

Despite a number of publications indicating the shortcomings and failures of the theory of constraints when attempting to implement premises of the theory of con-

straints in manufacturing companies it is a noticeable increase in interest in this theory. Some proponents of this theory proclaim that the Theory of Constraints has influential resurgence with emergence of a new generation of scientists in academic community that understand the conditions for applying the theory of constraints in today's strongly competitive business environment. It was also appointed a new association of practitioners, academics and students who want to improve the level of their competence in applying the theory of constraints. The association is called Theory of Constraints International Certification Organization (TOCICO). Its main task is to certify leaders involved in the theory of constraints according to standard guidelines developed by the organization. With the emergence of TOCICO a new era has begun in the field of operational management wherein the theory of constraints plays a significant role as the basic approach of management accounting.

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