USING THE THEORY OF CONSTRAINTS AND ACTIVITY-BASED COSTING FOR OPTIMAL PRODUCT MIX DECISION-MAKING IN METALLURGY

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Abstract

The decision of what amount of a product to produce in a specific interval may impact seriously corporate earnings. Various methods have been used to eradicate this problem. However, the Theory of Constraints scientific-oriented work represents the majority. This theory claims that at least one constraint is present in every system. In a production system the most frequently mentioned constraints are the capacity of machines or workers. In times of crisis, demand becomes one of the constraints especially for metallurgical centred companies. Therefore, the resolution of product mix related problems is crucial in metallurgy. This paper focuses on product mix decision-making with respect to the Theory of Constraints (TOC) and Activity Based Costing (ABC). Much research has been conducted on the application of TOC and the product mix problem using Dr. Goldratt's recommended solution. However, the latter does not lead to the optimal product mix in specific cases. The ABC emphasizes the causality of costs, activities and the final outcome. The method is based on the principle of processes that consume resources and outcomes that in turn, consume processes. This discussion presents the more developed solutions of the TOC and the ABC approach to this problem. The critical evaluation of the methods is performed and optimal procedure for the metallurgical industry is selected with recommendations for its use.

Keywords: product mix, Theory of Constraints, Activity Based Costing

1. INTRODUCTION

The business environment is always subject to changes and unstable development. The dynamic changes became more complex and competition hardens due to the turbulent environment. In recent years this process was even more rapid due to the changes within global conditions, among others, the financial crisis. As a result, we observe a decline of profitability in the period 2006 - 2009 [1] in the metallurgical industry in Central European countries. This corresponds with the lowest total productivity in 2009 [2]. The typical response of enterprises in times of declining profitability is to minimize costs. In the most common example minimizing costs signifies implementing LEAN instruments to eliminate parts of the system, which do not add value [3]. For business processes this includes process optimization.

The subject of optimization is in the broader context also the product mix decision. From the marketing view, the product mix is the set of all products and items that a particular marketer offers for sale [4]. However, in the perspective of production and process management product mix, it is defined as the optimal quantity of each product in a given period. The maximum amount of production is limited to the production capacity. When only one product is to be produced, then the optimal production quantity occurs when marginal sales equal marginal costs, as the neo-classical economy suggests for profit maximization. For the need to use more developed methods of product mix optimization, more assumptions are set [5, 6, 7]:

- More than one product is to be produced;
- Constrained resources;
- Constraints resulting from production planning;
- Constraints resulting from demand;

- Resources shared by more than one product.

With this definition the need for optimization is clear and a broad related scientific research, which addresses the aforementioned assumptions, has been conducted. However, not every research considers all of the assumptions. The majority of the authors transfer the product mix problem into linear programming with the objective function of profit maximization. The constraints reflected in this case are the production capacity and demand. Other authors consider linear programming to be an independent method of product mix optimization, but since the majority of product mix methods can be transferred into linear programming, it is used as a referral method to verify if the optimum was reached. In recent years the Theory of Constraints gained more attention in regards to product mix optimization. Activity based costing as a response to the lost relevance of traditional costing methods is implemented in a large number of companies.

The aim of this manuscript is to critically evaluate the TOC and ABC solutions to the product mix problem from the perspective of a profit maximizing firm. First, the TOC approaches are introduced, then the ABC approach are described.

2. METHODOLOGICAL BASE

2.1 The Theory of Constraints

The fundamentals of the Theory of Constraints were developed by Eliyahu Goldratt in the 1980s in his work entitled, *The Goal*. They were subsequently revised into the comprehensive form of the Theory of Constraints (TOC). The main objective of TOC is with the assistance of a repetitive process of identification, analysis and elimination of constraints adds value to a company. Each system (company), according to TOC, has to have at least one constraint, otherwise it could produce unlimited earnings [8].

The emphasis on managing the constraints is not completely novel; in a 1965 text we find a recommendation for companies to produce products with the largest contribution margin within a unit of limited factor [9]. The constraint does not have to be physical, but in most organizations rather concerns management.

To cope with this type of constraint with the aim of effectively implementing the process of ongoing improvement, TOC presents five steps [10]:

1. Identification of the system constraints;
2. Decision how to exploit the system's constraints;
3. Subordination of everything else to the above decision;
4. Elevation of the system constraint(s);
5. Are the constraint(s) still binding? Go back to (1), avoid inertia.

The subsequent term, which TOC uses to solve optimal product mix problem, is throughput. There is not a clear indication as to the definition of throughput. This is primarily due to the various definitions provided by Goldratt. Some researchers define throughput as a rate at which a system generates revenue through sales [11]. For the purpose of product mix decision-making is the most used definition: *throughput is sales price minus material costs. It is clear, that throughput resembles contribution margin.* The question remains whether the material costs are the only ones, which are variable, in a certain system. If not, then the second definition does provide biased results in product mix optimization. Given the correspondence with [11] it is more suitable to define throughput as sales price minus totally variable costs.

2.2 Activity Based Costing

Activity Based Costing relies on the relationship to activities. The method emphasizes the causality between costs, activity and the final outcome. Also specific overhead costs are traced to a specific product, not allocated on all products that a company produces. The nonmanufacturing overhead caused by products is allocated on a cause and effect basis. ABC demonstrates the effectiveness to which individual resources are used and how individual activities contribute to the costs of a specific product. The activities are divided into five levels [12] - see **Table 1**.

Table 1 Activities of the ABC

Activity	Costs
Activity to sustain the organization	Heating, company management, arranging for loans
Activity at the consumer level	Sales calls, catalog mailings, general technical support
Activity at the product level	Product design, maintaining a product manager
Activity at the batch level	Transport of material, purchasing orders, inspection
Activity at the unit level	Direct labor, direct material, costs on a specific machine and energy

3. EXPERIMENTAL DISCUSSION

In this part the individual procedures to determine the product mix are briefly introduced.

3.1 TOC heuristics to product mix determination

The TOC heuristics for optimal product mix use only the first two steps of the five steps process, the heuristic develops the optimal product mix as follows [8]:

Step 1: Identification of the systems constraint: Calculate the demanded capacity of each resource when all products are produced. The bottleneck is the resource, wherein the demand exceeds its capacity.

Step 2: Exploit the system’s constraint: Calculate the throughput of each product. Calculate the ratio of throughput of each product in processing time at the bottleneck. Reserve the bottleneck’s capacity in a decreasing order of the products throughput to processing time ratios. Finally, plan the production of products that do not use the restrained resource according to the decreasing order of their throughput.

However, the original TOC heuristics do not reach optimal solution in the case of multiple bottlenecks. Most researchers tend to orient the TOC heuristics to the constraint with the most excessive demand, but this solution was also proven suboptimal [8]. This is resolved by the further development of the heuristics into a revised algorithm. A neighborhood search is implemented to set the bottlenecks into order [13]. If every resource is used by every product, then the order of bottlenecks descends according to their excessive demand. Otherwise, the product should be scheduled into production based on their non-ascending order of their contribution margin to bottleneck resource processing time ratio. This continues until either market demand is met, or at least one of the constrained resources is exhausted. If the first exhausted resource was not the first one according to the excessive demand, this resource becomes the first in the order. Then, the time left on the bottlenecks is calculated. Afterwards the neighborhood search is conducted by reducing the quantity of a product, which uses the dominant bottleneck, one unit at a time. This creates capacity for the next product to be produced. When this action produces a non-negative contribution margin gain, then the new product mix is more profitable. The algorithm stops when the contribution margin gain is less than zero or the solution is not feasible.

Even this revised algorithm does not reach the optimum, and the simplicity of the original solution is also lost. This is why the improved TOC algorithm was proposed [14]. The multiple bottleneck problems are solved as a multiple-objective decision making problem. The bottlenecks are compiled into an ascending order according to the difference between available capacity and demanded capacity. Moreover, the products are ordered in each bottleneck. This sequence is the same, as in the revised algorithm according to the contribution margin to bottleneck resource processing time ratio. Then, the optimality of the initial solution is verified. This is performed not by conducting a neighborhood search, but by identifying candidate products for decrease and increase. The candidate product is identified by three conditions: its demand is not fully met, it is prior to other product in at least one of the bottlenecks sequences and in that sequence it is also prior to other products. It also retains algorithm simplicity with only 8 steps.

3.2 ABC solution of product mix optimization

The presented solution is a transformation of the product mix to linear programming [15].

$$Max \sum_{ii=1}^{n} \left\{ (s_i - m_i - lb_i) - \sum_{j=1}^{r} c_{ij} \left\langle \frac{x_i}{a_{ji}} \right\rangle \right\} \tag{1}$$

Subject to:

$$\sum_{i=1}^{n} m_i x_i \leq M \tag{2}$$

$$l_i \leq x_i \leq u_i, i = 1,\dots,n \tag{3}$$

$$\sum_{i=1}^{n} lb_i x_i \leq L \tag{4}$$

$$\sum_{i=1}^{n} c_{ji} \left\langle \frac{x_i}{a_{ji}} \right\rangle \leq o_i, j = 1,\dots r \tag{5}$$

x_i - denotes the amount if product *i* to be produced in a certain time period, *n* is the overall amount of various products. s_i is the selling price of product *i*. m_i is the material cost per unit of product *i*, lb_i is the labor costs per unit of product *i*, *M* is the monetary formulation of maximal available amount of a resource. *L* is the monetary denomination of maximal available amount of labor. u_i denotes the upper bound of product *i* and l_i is the lower bound. *r* is the overall amount of indirect resources. a_{ji} is the upper bound of the overall number of product *i* that can be produced from the resource *j* which costs c_{ji}. o_j denotes the monetary equivalent of maximum available resource *j*. $\langle {}^{x_i}/_{a_{ji}} \rangle$ is the smallest integer equal or greater to ${}^{x_i}/_{a_{ji}}$.

If we convert the TOC solution to linear programming, it appears almost the same, but the major difference occurs. Direct labor is often not considered to be a variable by TOC researchers. This reverts to the previously discussed issue as to the definition of throughput.

4. RESULTS AND DISCUSSION

The above-mentioned procedures to determine product mix are usable in metallurgical industry only with some adjustments and recommendations based on the chosen specifics of the industry, as stated in [16] and [17].

Floating capacity bottlenecks, the workplaces or devices that tend to become bottlenecks depending on the portfolio of products processed, are regarded as the basic constraints in metallurgical processes. This may be due to the relatively small use of TOC in metallurgy [16].

Because of the presence of floating bottlenecks, the original solution does not reach the optimum. As multiple bottleneck occur in the majority of metallurgical processes, the original solution is not regarded as suitable from this point forward. The revised algorithm solves the multiple bottleneck problems as single objective problem focus on the dominant bottleneck. For this reason, the improved algorithm appears more appropriate for use in metallurgical industry as it treats the issue as a multiple objective decision-making problem. The ABC approach in the linear programming transformation is not recommended, as it depends on the specific conditions of a specific company and its work contracts, whether to handle direct labor as a variable or fixed cost.

The specifics of the technological and technical basis of metallurgical processes implicate the use of the product mix procedures to some extent, especially its importance. Large quantities of products with different combinations of sizes, grades, shapes and heat treatment increase the computational complexity if the revised algorithm with the neighborhood search is used.

The demand of material and energy within metallurgical processes implies the need for the bottleneck utilization. The energy losses in an underutilized bottleneck are significant in the case of certain productions. The revised algorithm compared to the improved algorithm does not prove the optimum throughput in the optic of all bottlenecks, but only within the dominant. For this reason the revised algorithm is not recommended.

Large production batches and volume processed in a single cycle, especially batch production, constitute another reason for bottleneck exploitation. In turn, this leads to the recommendation of the improved algorithm. Moreover, the increasing diversity of the product range of metallurgical companies increases the computational demand for the neighborhood search in the revised algorithm.

The high demand for organizational and operational planning and control in metallurgical processes is the last considered specific. The variability of production routes and the often irrational deployment of production deployment is the reason for the corresponding demand. For the use of product mix determination this signifies that the necessary inputs in the procedures cannot always be easily retrievable or even known in the correct form. This leads to the existence of multiple and often floating bottlenecks, which are better handled by the improved heuristics.

The ABC method is limited specifically in the sense of required informational inputs. Companies that implement the ABC can of course use the ABC information to determine its product mix and benefit from the more accurate determination of fixed and variable costs.

CONCLUSION

The more developed TOC solutions to product mix optimization are introduced and the linear programming transformation of the ABC product mix determination is stated. The implementation of the procedures in the metallurgical industry is limited by industry specifics. The multiple (floating) bottleneck nature, technological and technical basis, material and energy demand, large production batches and volumes processed in a single cycle and high demand for organizational and operational planning and control of the processes represent the main. Due to the computational complexity, better multiple bottleneck handling, multiple objective decision-making approaches to the problem and a relatively simple use of the 8-step heuristics, the improved algorithm is recommended. The ABC is suitable in the sense of a more accurate determination of fixed and variable costs, with the premise that the ABC has been implemented.

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