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CRITICAL CHAIN PROJECT MANAGEMENT AND DRUM-BUFFER-ROPE TOOLS INTEGRATION IN CONSTRUCTION INDUSTRY - CASE STUDY

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ABSTRACT. Background: The concept of integrating the theory of constraints tools in reorganizing management system in a mechanical engineering company was presented in this article.
The main aim of the concept is to enable the enterprise to satisfy the customers' expectations at reasonable costs, which allows for making a profit and creating an agile enterprise in the long run.
Methods: Due to the individual character of the production process and service process in analyzed company, the described concept using theory of constraints project management (CCPM) and manufacturing (DBR) tools. The authors use performance levels conception to build an integration tool focused on the interaction and collaboration between different departments. The integration tool has been developed and verified in Polish manufacturing company.
Results: In described model a tool compatible with CCPM operates on the level of the customer service process. Shop floor is controlled based on the DBR method. The authors hold that the integration of between TOC tools is of key importance. The integration of TOC tools dedicated to managing customer service and shop floor scheduling and controlling requires developing a mechanism for repeated transmitting the information between them. This mechanism has been developed.
Conclusions: The conducted research showed that the developed tool integrating CCPM and DBR had a positive impact on the enterprise performance. It enables improving the company performance in meeting target group requirements by focusing on enhancing the efficiency of processes running in the company and tasks processed at particular work stations. The described model has been successfully implemented in one of the Polish mechanical engineering companies.

Key words: Critical Chain Project Management, Drum-Buffer-Rope, process integration, company effectiveness.

INTRODUCTION

Globalization processes and increased market competition force organizations to reorganize production processes to reduce lead time and manufacturing costs. These objectives are in logical conflict. How to conduct manufacturing operations oriented on unit orders and remain competitive with standard solutions produced with the application of the scale effect?

The authors of this paper conducted research and development works at a mechanical engineering enterprise, which used the theory of constraints tools to streamline the current management of basic operations (customer service and manufacturing processes). It was observed that deployment of the Critical Chain Project Management and Drum-Buffer-Rope did not yield the expected results. The problems encountered prior to the implementation were only partly solved. The authors hold that it was because the tools had a local impact. The flow of information between them was inadequate, which obliterated any positive effect in the entire company. The aim of this paper is to present the tool designed by the authors for the purpose of integrating the theory of constraints tools.

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THEORETICAL BACKGROUND

Theory of Constraints tools

Theory of Constraints (TOC) has been proposed by Eliyahu Goldratt. TOC has been developed as a theory of continuous improvement of the enterprise business operations. Five steps for enhancing an organization performance, developed by the author of the theory [Goldratt 2004]:

1. Identify the constraint.
2. Decide how to exploit the constraint.
3. Subordinate and synchronize everything else to the above decisions.
4. Elevate the performance of the constraint.
5. If, in any of the above steps the constraint has shifted, go back to Step 1.

To proceed with the subject, continuous improvement consistent with TOC may occur on three planes. The highest level involves processes taking place across the entire organization and the interrelations between them [Gupta, Boyd 2008]. Streamlining the system at the highest level is possible thanks to continuous improvement described in 5 steps. At the operational (2nd level), TOC suggests applying the Logical Product Structure (LPS) method and V-A-T analysis. LPS method results in the information on the flow of materials and components of the product analysed by the enterprise, including all the operations, starting from raw materials up to a finished product [Gupta, Boyd 2008]. V-A-T analysis allows for determining the location of buffers in a manufacturing system [Hadas, Cyplik, Fertsch 2009]. At the detail-oriented (3rd level), TOC proposes applying the concept of Drum - Buffer - Rope (DBR) manufacturing system management. Streamlining the production system according to TOC is connected with [Wu, Yeh 2006]:

1. increasing the system throughput (amount or value of products per time unit);
2. reducing work in process;
3. shortening production cycles and improving on-time order delivery.

All the advantages listed above are geared towards greater customer satisfaction and lower operational costs.

There are 3 components in the DBR concept, which allow for increasing a manufacturing system throughput. The first component is Drum - the system constraint that sets the production pace. An overriding importance of the constraint follows from TOC assumptions, in particular from the 2nd step in the system improving - 'exploiting' the bottleneck. Buffer - a kind of protection (time or materials) from disruptions occurring at the preceding processing step. Rope - a mechanism ensuring that all the system components work at a pace set by the bottleneck, which will reduce work in progress level [Koh, Bulfin 2004].

An ever-growing importance of projects in the company management has been noticed by the authors writing on TOC. It gave rise to a new method of project management evolved, based on the so called Critical Chain - Critical Chain Project Management (CCPM). Critical Chain is a set of interrelated tasks with the longest completion time, taking into account the system resource constraints. The constraints are, among others: the availability of funds, time, multitasking etc. In scheduling the use of resources, individual tasks in the critical chain have no time buffers and are scheduled backward (postponing until the last moment) [Robinson, Richards, 2009]. Introducing the latest start times possible and shortening their duration by removing time reserve requires estimating and scheduling measures compensating for any natural deviations and the events of multitasking [Rahman, 2004]. There are two basic time buffers:

1. Project buffer - inserted at the end of the project, ensures its timely completion. Buffer size is often described as half the size of the critical chain [Stratton, Knight 2010].
2. Feeding buffer - inserted at the end of tasks not included in the critical chain, protecting the critical chain [Herroele, Leus, Demeulemeester 2002].

Improving performance

Gaining competitive advantage can be gained in the conditions described in the introduction can take place through continuous performance improvement. Performance is defined as: 'the degree to which an employee or a group applies skill and effort to an operation or task as measured against an established standard' [Blackstone, Jonah]. Improving performance ought to take place at three levels: organization, process and work stations. Managers willing to improve performance at the organization level should focus on setting goals that reflect the organization's values and the customers' requirements. At the next level the key are efficient basic processes in business operations. It combines the last two levels, thus opening up greater performance improvement opportunities. The last but not least level of enterprise performance is the performer level, referred to every single work station. Performance management at the lowest level may only produce a result that is marginal in terms of what could be achieved [Rummler, Brache 1990].

TOC highlights the need for surrendering local optimums in favour of global optimums. Decisions made based on local performance measures could adversely affect the entire system [Mabin 2003]. Benefits from seeking global optimums can be enjoyed thanks to an internal integration defined as "the quality of the state of collaboration that exists among departments that are required to achieve unity of effort by the demands of the environment' [Lawrence, Lorsch 1967]. Nowadays, in the era of SCM, internal inter-functional integration is focused on the interaction and collaboration between different departments [Ellinger, Daugherty Keller 2000] and it will be understood as such in the course of this paper.

CURRENT STATE ANALYSIS

The enterprise described in this paper specializes in manufacture of equipment for pumping water and wastewater. The nature of customer needs and requirements calls for providing highly customized solutions. In the enterprise under analysis customer service is unit in nature, which makes the process akin to project implementation.

The Production System Virus Analysis (PSVA) [Cyplik, Hadas 2011] was applied to identify the problems responsible for the company's failure to complete unit orders at an acceptable cost.

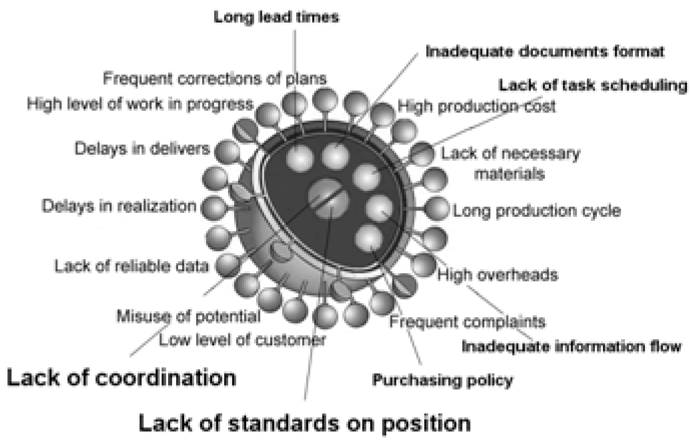

Fig. 1. Production System Virus in analyzed company
Rys. 1. Wirus systemu produkcyjnego analizowanego przedsiębiorstwa

Fig. 1 presents root problem occurring in the company. TOC tools have been deployed to solve them. The CCPM tool was selected to streamline customer service management. By implementing the methodology and support IT tools the managers obtained the information on the progress of each project and the level of time buffer exploitation. The DBR tool was applied to improve the shop floor operations. It was supposed to reduce work in process inventories and the manufacturing process time.

THE INTEGRATION OF TOC TOOLS

The implementation of TOC tools in the analysed company resulted in sorting out the activities performed as part of customer services. The measures illustrating individual processes showed improvement, yet the overall effectiveness across the company failed to achieve the assumed level. In reference to the diagnosed problem, the authors emphasized the need for perceiving the company as a total of work stations and processes performed there. While striving to improve the performance of conducted business it is necessary to seek potential reserves at each work station. An enhancement of the effectiveness of operations at work stations is followed by an improvement in the processes. In line with the process approach, an organization consists of the processes it performs. Hence a simple conclusion that if process efficiency is improved, the entire enterprise benefits.

Assuming the above, the authors attempted to systematize the levels of efficiency in the analyzed company. From the organization point of view, customer service is of prime importance. It is directly related to new order winning, their completion and timely delivery of products to the customer. From the customer service point of view it is manufacturing that is crucial. This is due to not only to the processing of raw materials, materials and components into the finished product, but also owing to high cost-consumption and numerous difficulties leading to late deliveries to customers.

The decision to implement the project management tool was inspired by the nature of customer service processes, making it akin to project implementation, the possibility to implement the tool in the existing ERP system and the benefits in the form of enhanced process efficiency and reduced completion time. It had been assumed that this tool will enable the improvement of performance at the process level.

At the level of work stations it was decided to implement the DBR tool, because it allowed for easy shop floor control. Shortening production cycles and reducing work in process inventories was supposed to enhance shop floor performance.

Research conducted following the implementation of the solutions suggested by TOC did not support the assumptions. According to the authors, the reason behind it was a lack of coordination between individual components of the customer service process, with considerable emphasis on the production process. Streamlining activities were local in nature and their impact on the entire organization was negligible. Based on these observations the authors observed the need for integrating the existing TOC tools. The integration scheme is presented in Fig. 2.

Fig. 2 illustrates the application of TOC tools in the context of building up the organization efficiency. A tool compatible with CCPM operates on the level of the customer service process. Shop floor is controlled based on the DBR method. The authors hold that the integration of between TOC tools is of key importance. Input information on the requested production process due dates, the extent of buffer exploitation, the order of devices to be produced are critical for proper shop floor control. As the shop floor organization is consistent with the DBR principle, this information is used as input data to queue work at the bottleneck, which controls the process of pulling materials according to the 'pull' logic. The materials pulled in the manufacturing system are pushed between individual work stations in line with the 'push' logic. On the assumption that all work stations on the shop floor are more efficient than the bottleneck, such measure is expected to minimize work in process. The production system pulls as many resources as the system constraint allows. Other work stations do not reach their maximum throughput, because it would result in accumulating work in process and, on top of that, would not shorten the duration of the shop floor process. Therefore, by cutting the manufacturing costs its effectiveness is raised, assuming throughput is the same. This assumption is valid on account of the fact that bottleneck manufacturing capacity remains unchanged. The information from the project management tool to the shop floor management is as important as important as the information sent the other way round. In the proposed model the shop floor objective is to produce finished goods and take care of the quality of the information sent to the project management tool. If manufacturing is to be treated as one of the stages of the customer service process, it is necessary to report on the work progress and expected completion dates. Any problems likely to affect the scheduled date of product delivery should be reported and such knowledge should be used for making decisions in providing service to a given customer.

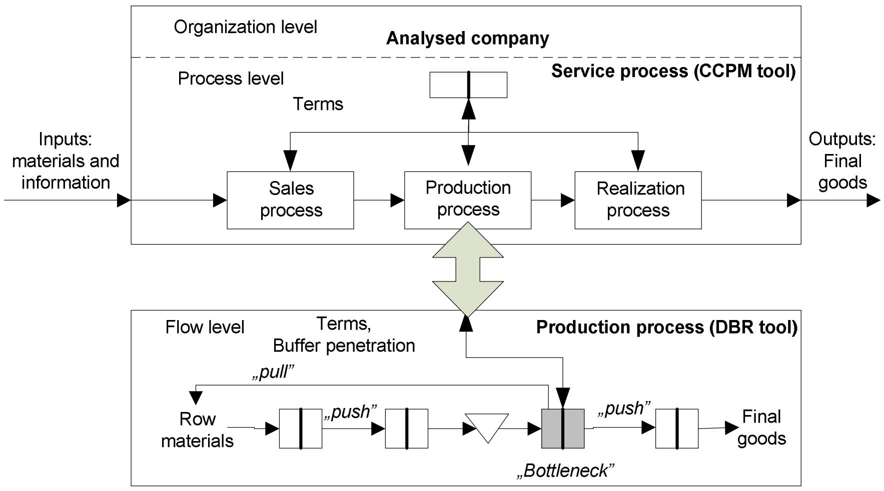

Fig. 2. TOC tools integration
Rys. 2. Integracja narzędzi teorii ograniczeń

In the course of optimization, many a time the shortening one of subprocesses does not reduce the time of the entire process. It is caused by losses sustained while waiting for the execution of the subsequent subprocess resulting from multitasking. Then all the effort taken for the purpose of achieving local optimization is frustrated. In reference to the situation under analysis, even though the enterprise implemented TOC tools, generating the information on the progress of each process, such information was not put to any use at subsequent links. The persons in charge of scheduling and controlling shop floor did not know the actual priorities of pending production tasks. The only shop control information provided was the scheduled date of shipment to the customer. Task queuing with a view to the presented criterion led to numerous problems in executing tasks with a lower priority. As part of tool integration it was necessary to develop a tool determining the actual priorities in implementing production tasks. The solution to this problem is presented in subsequent chapters of this paper.

PARAMETERIZATION OF THE INTEGRATION TOOL

The integration of TOC tools dedicated to managing customer service and shop floor scheduling and controlling requires developing a mechanism for repeated transmitting the information between them. Its basic objective is the prioritization of tasks in terms of the assumed criterion. The goal of the enterprise is to maximize shareholder value [Pitman 2003, Sundaram, Inkpen, 2004]. For this purpose profitable activity must be conducted. Hence, in the context of system constraints, the need for taking measures aimed at yielding the greatest profits from the point of view of the maximum bottleneck exploitation.

Starting deliberations from the customer service level, one should focus on the profitability of each project, either in process or potential. An indicator reflecting the real profitability of a project is profit per man hour generated by the system constraint.

$$pb_x = \frac{pr_x}{\tau_x} \left[\frac{\$}{h}\right]$$

pb_x - profitability of bottleneck in project x

pr_x - project x profitability [$]

τ_x - use of bottleneck [h]

If we know the bottleneck profitability values of each project, they can be sorted in descending order of the indicator value. Thus the company can be confident that with certain resources at its disposal, it will select the most profitable projects out of a set of projects. This can be applied in the sales department responsible for seeking new orders. Accepting new orders would depend on the profitability index compared with other potential orders. Orders accepted via the project management support tool are divided into tasks and assigned to individual departments. The project manager is obliged to set deadlines for completing each project stage by the departments in terms of available resources and the scheduled product delivery date.

The integration of project management and shop floor control tools requires determining priorities for filling manufacturing orders in the context of the information obtained from customer service. To avoid decisions that could be chaotic or not urgency-driven, the authors developed a two-stage prioritization scheme. A priority index matrix was used for this purpose. The first stage of creating a matrix is calculating the priority index for each production order in the work queue. Production order contains a tool constituting a component of the project developed for the customer.

$$pi_{xy} = \frac{c_x}{e_{xy}}$$

pi_{xy} - priority index of the X device towards the Y device

c_x - importance of the customer ordering the X project

e_{xy} - bottleneck changeover time - from processing the Y device to the X device

The customer importance parameter must be known to calculate the priority index. It is important for making decisions on the order in which production orders will be filled. If on-time delivery of orders is jeopardized, the orders placed by profitable and prospective clients take priority. The next parameter used for determining priority index is changeover time at the production system bottleneck. It should be minimised to be exploited to the full. Hence, orders with shorter changeover time are given higher priority. As it is required to display changeover times must be presented in a matrix system (changeovers between particular devices), priority index also creates a matrix. The priority index matrix system is presented in Table 1.

Priority index is determined for each changeover variant between any two devices awaiting completion in a production system. For reliable information on the urgency of each order, shop floor controller should take into account the extent of time buffer use for each project and, respectively, devices.

Table 1. Priority index matrix
Tabela 1. Macierz wskaźników priorytetowości

	Device $_x$	**Device $_y$**	**…**	**Device $_z$**
Device $_x$				
Device $_y$				
…				
Device $_z$				

The next stage of developing the CCPM and DBR integration tool would be to make it possible to apply priority index colours on the presented matrix, which would be reflective of the buffer use status, provided for each project. According to the traffic light analogy logic, low buffer penetration (buffer consumption of less than 1/3) is marked with green; medium buffer penetration (buffer consumption between 1/3 and 2/3) is yellow, whereas deep buffer penetration (over 2/3) - red [4]. The information on the buffer penetration status is sent from a customer service management support tool. The data on the actual buffer use is sent every time the queue of devices awaiting processing is refreshed. It can be either automatic upon moving the order to the processing stage, every given time interval, or manual - at the request of shop floor controller. Thus the worker deciding on the order of works on the shop floor can choose in the first place the devices with the highest (red) priority - the most urgent ones, intended for the most important customer and with the lowest changeover time, which allows for reducing waste at the bottleneck.

The major advantage of the described integration tool is providing the information on the actual priority of each production task. Thus, the managers will be confident that the most urgent tasks from a given set are processed in the first place. It allows for reducing their completion times and improving product delivery timeliness. The enterprise resources and, first of all, the resources constituting the bottleneck, are the tasks most profitable for the organization. This, in turn, translates into an enhanced performance of the enterprise.

CONCLUSION

The tool presented in this paper has been tested as part of research and development works. It was decided to apply 4 logistic measures. The research was conducted in two 6-month periods: prior to and following the implementation. The analysed periods involved estimated demand distribution and the characteristics of placed orders. In the context of the tool implementation the first measure under analysis was Dock to Dock Time (DDT). Following the implementation its average value fell by 12 per cent, which is reflective of an increase in the material flow across the enterprise and its greater flexibility. Reducing lead times should go hand in hand with their timeliness. Order timeliness is measured by the On Time In Full (OTIF) performance indicator. The number of orders delivered on time and in full rose by 4 per cent. Production scheduling and shop floor control were analysed using the production flow control efficiency indicator, showing the number of production orders processed on schedule compared with the total number of orders. As production scheduling did not function properly before the implementation, the indicator went up by as much as 56 per cent. What is vitally important, the suggested solution reduced not only the time of material flow, but also costs. The Stock Coverage (SC) was examined in terms of value for overall stock (raw materials, work in process, finished goods). After the implementation the indicator went down by 17 per cent, resulting in cash release and improved financial situation of the enterprise.

The conducted research showed that the developed tool integrating CCPM and DBR had a positive impact on the enterprise performance. It enables improving the company performance in meeting target group requirements by focusing on enhancing the efficiency of processes running in the company and tasks processed at particular work stations.

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INTEGRACJA NARZĘDZI ŁAŃCUCHA KRYTYCZNEGO ORAZ WERBEL-BUFOR-LINA W BRANŻY BUDOWY MASZYN - CASE STUDY

STRESZCZENIE. **Wstęp**: Artykuł prezentuje koncepcję integracji narzędzi teorii ograniczeń wykorzystaną do reorganizacji funkcjonowania przedsiębiorstwa z branży budowy maszyn.

Głównym celem prezentowanej koncepcji jest umożliwienie przedsiębiorstwu zaspakajania potrzeb klientów po racjonalnych kosztach, co ma w konsekwencji doprowadzić do zwiększenia zysków a w perspektywie długofalowej do zbudowania zwinnej organizacji.

Metody: Ze względu na jednostkowy charakter procesów produkcji oraz obsługi klienta opisana koncepcja wykorzystuje znane z teorii ograniczeń narzędzia: łańcuch krytyczny oraz werbel-bufor-lina. Autorzy wykorzystali również poziomy efektywności organizacji do zbudowania narzędzia w celu integracji poszczególnych działów przedsiębiorstwa. Zaprezentowany model został opracowany i z sukcesem wdrożony w jednej z polskich firm z branży budowy maszyn.

Wyniki: W opracowanym modelu narzędzie CCPM funkcjonuje w obszarze obsługi klienta natomiast narzędzie DBR odpowiada za kontrolę sterowania produkcją. Integracja obu narzędzi wymagała również stworzenia mechanizmu przepływu informacji pomiędzy nimi.

Wnioski: Przeprowadzone badania pokazały, że stworzone narzędzie integrujące CCPM oraz DBR miało pozytywny wpływ na efektywność jednego z polskich przedsiębiorstw z branży budowy maszyn. Pozwoliło na poprawę spełniania wymagań klienta poprzez wzrost efektywności procesów funkcjonujących w przedsiębiorstwie oraz zadań realizowanych na pojedynczym stanowisku roboczym.

Słowa kluczowe: łańcuch krytyczny, werbel-bufor-lina, integracja procesów, efektywność przedsiębiorstwa.

PROJEKTMANAGEMENT DER KRITISCHEN LOGISTIKKETTE UND DIE INTEGRATION DES WERKZEUGES AM BEISPIEL DES TROMMEL-PUFFER-SEILES IM MASCHINENBAU - EINE CASE STUDY

ZUSAMMENFASSUNG. Einleitung: Der Artikel präsentiert ein Konzept für die Integration der Werkzeuge der Theorie von Begrenzungen, die bei der Reorganisation der Funktionsausübung eines Unternehmens aus der Branche des Maschinenbaus in Anspruch genommen werden. Das Ziel des dargestellten Konzeptes ist es, dem Unternehmen die Erfüllung von Bedürfnissen seiner Kunden zu rationellen Kosten zu ermöglichen. Das sichert auch die Erhöhung der Gewinne und in der Langzeit-Perspektive den Aufbau einer agilen Wirtschaftsorganisation.
Methoden: In Hinsicht auf den komplizierten Charakter von Produktionsprozessen und der Kundenorientierung nimmt das beschriebene Konzept die von der Theorie von Begrenzungen her bekannten Werkzeuge: der kritischen Logistikkette und des "Trommel-Puffer-Seiles" in Anspruch. Die Autoren haben zum Aufbau eines Instruments zum Zwecke der Integration der einzelnen Abteilungen eines Unternehmens auch das Niveau der Effektivität der jeweiligen Organisation einbezogen. Das präsentierte Modell ist in einer polnischen Firma des Maschinenbaus ausgearbeitet und erfolgreich eingeführt worden.
Ergebnisse: Das CCPM-Werkzeug funktioniert innerhalb des konzipierten Modell im Bereich der Kundenbedienung und das DBR-Werkzeug ist für die Kontrolle der Produktionssteuerung verantwortlich. Die Integration der beiden Tools bedurfte auch des Aufbaus eines Algorithmus zur Integration des Informationsflusses zwischen ihnen.
Fazit: Die durchgeführten Untersuchungen haben gezeigt, dass das geschaffene Werkzeug, die CCPM und DBR integrierende Werkzeugvariante die Effizienz eines polnischen Maschinenbau-Unternehmens positiv beeinflusst hat. Es erlaubte eine verbesserte Erfüllung der Kundenbedürfnisse und -anforderungen infolge der erreichten Erhöhung der Prozess-Effektivität im Unternehmen und auf dem einzelnen Arbeitsplatz bei der Ausführung von konkreten Produktionsaufträgen.

Codewörter: kritische Kette, Trommel-Puffer-Seil, Prozess-Integration, Effizienz eines Unternehmens.

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