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IMPLEMENTATION OF THE THEORY OF CONSTRAINTS IN THE AREA OF STOCK MANAGEMENT WITHIN THE SUPPLY CHAIN – A CASE STUDY

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ABSTRACT. Theory of Constraints (TOC) is a philosophy of management put forth by Eliyahu M. Goldratt, which claims that each system has at least one constraint. This philosophy is applied in many functional areas of companies, ranging from production flow management, marketing, accounting or project management to being a tool of logical reasoning. In this paper, the authors show how the Theory of Constraints can be applied in supply chains, with special attention paid to TOC-based stock management principles which are implemented in the pharmaceutical industry. A practical example described by the Authors illustrates the possibility of creating hybrid solutions combining TOC with other methods.

Key words: TOC, stock management, stock replenishment models.

INTRODUCTION

The Theory of Constraints (TOC) was developed by an Israeli physicist E. Goldratt. The TOC concept was initially used only in the production environment (it was previously known by the name of Optimization Production Technology, OPT), however today there are many examples of TOC application both in distribution, procurement and marketing, i.e. various areas of supply chain management. TOC is a method which has a well-developed research apparatus referred to as the Thinking Process. The mechanism makes it possible to analyse systems and to identify and remove any constraints which act like obstacles preventing the company from achieving its goals. Constraints also include "bottlenecks", i.e. weakest links within an enterprise which, in critical situations, are first to become sources of problems. If they are not promptly removed, they adversely affect the development of the enterprise or supply chain (e.g. in the aspect of production or financial liquidity). Application of the Thinking Process in the Management of enterprises which function as links in the supply chain makes it possible to establish robust standards in such areas as development of strategies, HR management, sales and marketing, finances and creation of coherent systems for measuring economic efficiency.

In addition to the basic measure of production value, assessment of the degree of goal achievement in the TOC framework also involves stock, i.e. capital "frozen" in materials. The aim of each system should be striving to increase the volume of sold production, ensuring a reduction of stock levels and operating expenses and, at the same time, contributing to an increase in profits.

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The implementation of TOC should make it possible to reduce costs of material flow through the supply chain. Appropriate stock allocation for different links within the supply chain, coupled with the application of suitable models of stock replenishment, is the basis for cost optimisation.

In this article, authors seek to outline the possibilities of using TOC as an element of a hybrid system for stock management in supply chains.

CONSTRAINTS-BASED APPROACH TO SUPPLY CHAIN MANAGEMENT

A constraint-based approach is defined as a method which introduces beneficial changes and mitigates adverse effects of constraints on supply chain profitability. Changes made within this approach focus on activities associated with constraints management which might ultimately contribute to increasing supply chain profitability. There are two basic ways in which the constraint-based approach improves the supply chain. One of them is to provide reliable measures of general results to help individual links in the chain to assess their progress in the achievement of the total supply chain income which they generate. The other focuses on enhancing efforts which have a major impact on supply chain results. This study is primarily oriented at analysing the former approach.

MEANS OF ASSESSING SUPPLY CHAIN PROFITABILITY

Supply chains are systems developed with a view to achieving specific goals, usually earning money. Therefore, to determine whether a supply chain fulfils its objectives, three main factors are considered: throughput, investment and operating expense.

Throughput mainly consists of income and refers to the rate at which the supply chain generates sales income, as well as measuring capital flowing into the supply chain from the outside.

Investment represents all resources (typically raw materials or purchased batches of goods) invested by the supply chain into goods that the chain seeks to sell. This definition of the concept excludes the added value of labour and overhead costs. The following forms of investment occurring within the supply chain can be distinguished:

- raw materials,
- finished goods (unsold),
- work in progress.

Operating expense - a total of financial resources spent within the supply chain to transform investment into throughput. They refer directly to labour, overhead costs and fixed expenditure (independent of production volume).

All the factors listed above are interdependent. Any change occurring in any of them affects the others. Consequently, according to TOC assumptions, in order to improve the efficiency of operation of the system as a whole, efforts should be made to increase as far as possible the value of sold production based on optimisation of stock levels and maximum reduction of operating expense.

The most important added value generated by activities taking place within the supply chain is capital. According to the definition, throughput is determined as sales minus sales discounts, expenditure and actual variable costs.

As a result:

Unit throughput = Unit sales - expenditure - variable costs

or:

Total throughput = Unit throughput x number of units sold

Supply chain profitability can be defined using the following indicators:

Net profit (NP) - the net profit of a supply chain is equivalent to throughput minus operating expense for a particular period:

$$NP = T - OE \text{ ,}$$

Productivity (P) - the productivity of a supply chain is basically equivalent to the ratio of throughput to operating expense:

$$P = \frac{T}{OE} \text{ ,}$$

Return on investment (ROI) - the return on investment within a supply chain can be defined as the ratio of net profit to investment (in materials and others):

$$ROI = \frac{NP}{Investment} \text{ ,}$$

Capital flow (CF) - the capital flow of a supply chain is equal to net profit plus/minus changes in investment for the respective period:

$$CF = NP \pm \Delta I \text{ .}$$

Due to the interdependency of logistic processes within the supply chain, the majority of activities have a minor influence on the profitability of the supply chain. Only those activities that focus on constraints, together with effects of improvements, can have a significant positive impact on the operation of the supply chain [Simatupang, Wright, and Sridharan 2004].

FIVE-STEP THINKING PROCESS

The Theory of Constraints as a way of thinking aims at constantly increasing the efficiency of the system. Each supply chain is targeted at generating profits, however its inherent constraints (there is always at least one constraint present) make it impossible for all participants of the chain to reap unlimited benefits. In order to resolve the problem, all links in the chain should, first and foremost, recognise a constraint and then focus all activities and decisions on managing the constraint in such a way as to increase current and future gains. However, the decisive factor determining the implementation of efforts aimed at improving the operation of the supply chain is consensus as to the type and location of constraints.

In the constraint-focused process of supply chain improvement, the profitability of the entire supply chain is defined and determined by the constraint existing in a given supply chain. If the constraint is permanently removed, the supply chain can increase its profitability until another constraint comes up. Consequently, to increase the efficiency of the whole system, the TOC provides management tools in the form of a five-step procedure which, provided that it is followed consistently, yields beneficial outcomes [Reid 2007].

Step one: identification of system constraint

Identification of constraints that may occur both within and outside the supply chain is of vital importance. Supply chain constraints markedly reduce the throughput of the chain. Consequently, members of the supply chain should coordinate their efforts on removing the constraint, as that the outcome of chain operations as a whole depends on impact exerted by the constraint. It frequently happens that constraints develop because of local rules imposing reductions of production, distribution and marketing costs.

One example is the min-max principle used in defining stock levels. Under the method, as soon as the stock level falls below a predefined minimum level, an order is placed to replenish the stock up to the maximum level. The method seeks to reduce transportation costs; however in many cases a retailer has the same suppliers delivering different products to the warehouse. In this case, both the retailer and the supplier should review their stock replenishment policy to satisfy customer requirements.

Step two: decision to exploit the constraint

This stage comes down to deciding what actions should be taken to pool out the maximum benefits out of the constraint or, in other words, how to exploit the constraint to ensure the maximum capital flow for the company. This means optimisation of the capacity of the constraint which is not properly exploited by producing and selling unsuitable product sets and by inappropriate principles of constraint planning and controlling. The constraint should be subject to ongoing monitoring to make sure there is no downtime. At the same time, all activities should be scheduled to bring maximum gains: the focus should be on those products which, in the bottleneck analysis, generate the highest profits.

Step three: subordination of the entire system to the constraint

Adjustment of the scheme of operation of all activities within the system to the existing constraint.

Step four: reinforcement of the constraint

This step consists of increasing the constraint's capacity, i.e. improving its action. For example, the supplier can increase the capacity of the constraint by redesigning products, increasing stock or enhancing production capacity, which enables quick response to changing customers' demands.

Step five: return to step one

If a previously identified constraint has been eliminated, the system needs to be reassessed to verify whether the constraint has not relocated to another link [Cyplik, Hajdul 2008].

IMPACT OF DIFFERENT MEMBERS OF THE SUPPLY CHAIN ON THE OPERATION OF THE ENTIRE SYSTEM

General measures of the supply chain described above, as well as the five-step thinking process, indicate that there are two implications for supply chain participants.

One of them is the meaning of improvement of inappropriate principles of operation between different participants of the chain. The main rule states that members of the supply chain earn money when they sell products to the final customer. This means that the retailer receives money from the customer and afterwards other participants of the chain receive money from previous supply chain links relative to the throughput of the supply chain. The scheme encourages all links in the chain to concentrate on the throughput, as their individual profitability depends on the joint effort to increase the throughput of the entire supply chain.

Secondly, members of the supply chain are able to determine the progress of the initiative focused on constraining the chain, which automatically translates into increased supply chain profitability. Reinforcement of the constraint results in increased efficiency of operation of the chain as a whole which, as a result, produces higher profitability. An assessment of supply chain profitability can be performed using the measures enumerated above: NP, ROI and CF (compare section “Means of assessing supply chain profitability”).

In order to make it easier to understand the impact of operating decisions on throughput, investment and operating expense within the supply chain, the following suggestions are proposed [Simatupang, Wright, Sridharan 2004]:

If throughput equals total sales income (∑SR) reduced by total variable costs of sales (∑VS), and - at the same time - net profit (NP) is equivalent to throughput (T) minus operating expense (OE),

$$T = \sum SR - \sum VS$$

and

$$NP = T - OE \,,$$

answering "yes" to questions listed below means that taking operating decisions would improve net profits:

– "Will sales pick up?",

– "Will this speed up response?",

– "Will this reduce costs of materials?",

– "Will this reduce fixed costs?",

If ROI is equivalent to total sales income (∑SR) minus total variable costs of sales (∑VS) and operating expense (OE), divided by investment (I),

$$ROI = \frac{\sum SR - \sum VC - OE}{I} \,,$$

answering yes to the questions listed below means that operating decisions are likely to induce an increase in ROI:

– "Will the time between product delivery and payment date be reduced?",

– "Will the volume of sales over the corresponding period increase?",

– "Will the time between order placement and product delivery be prolonged?"

If capital flow equals total income from current sales of all products (∑SR) reduced by total variable costs of current sales of all products (∑VC) plus/minus investment changes (∑I),

$$CF = \sum SR - \sum VC \pm \sum I \,,$$

answering yes to questions listed below means that operating decisions are likely to increase capital flow:

– "Will surplus capacity decrease?",

– "Will constraint utilisation increase?",

– "Is it necessary to reduce resources, e.g. cut investment?",

– "Does this require stock level reduction?"

Using the guidelines above, members of the supply chain are able to assess whether their decisions trigger an improvement within the whole chain, which automatically ameliorates their operation.

APPLICATION OF TOC IN STOCK MANAGEMENT

Within the constraint-based framework, the stock replenishment policy should include certain prerequisite rules governing the adjustment of supply volume and demand in different points within the supply chain. In the supply chain based on the Make-to-Stock system, the constraint is often the final customer. Therefore, in order to exploit a constraint of this type, the supply chain should provide an appropriate product, at the right place and time. The idea behind this approach is to authorise those members of the supply chain who possess the most extensive knowledge to make decisions supporting an increase in the chain's profitability. For example, a retailer cooperating with a supplier is responsible for taking market initiatives (focusing on customer behaviours and product life), while the supplier's duty is to ensure quick delivery to meet the customer's needs.

LITERATURE-BASED APPROACH

In order to ensure efficient and effective operation of the system, the group of customers should be broken down into segments by various criteria such as product features, delivery time or crediting periods. The segmentation makes it possible to give priority to key customers and take good decisions with a view to improving the operation of the entire supply chain, thus contributing to a growth in profitability. The supply chain can then be classified into a variety of groups according to priority assigned to potential orders. The supplier, having in-depth knowledge of product design, is authorised to take decisions regarding product quantity and period of delivery to the retailer. Meanwhile, feedback received by the retailer from the market is used to forecast possibilities of stock replenishment when stock is determined by orders placed by the retailer with a certain time horizon. In line with this stock replenishment policy, sales would be secured if the supplier delivered what has been used up.

Stock in the following link of the supply chain serves as a buffer. The rate of buffer consumption reflects such factors as normal sales or seasonal sales etc. Consequently, to monitor changes in market demand and buffer quantity, the supplier applies buffer management.

A distinct feature of the constraints-based approach in the supply chain is that deliveries are effected on time, which is a definite strong point at times of demand fluctuations, and that appropriate standards of management are developed for individual links in the supply chain. What is more, stock levels are kept low, which translates into lower costs as products are not stored at consecutive links in the chain. Whenever a need arises, they are supplied. Instead, there are several points where stock is stored to take into account consumption variations. To improve the overall result, the supplier can strategically place buffers in points of key importance.

The location of three focal points along the supply chain, i.e. retailer, warehouse and production buffers, is represented in Fig. 1.

The warehouse keeps an appropriate stock level to satisfy the customer's demand, taking into consideration the inventory replenishment cycle time within a specified time unit. Consequently, buffer levels in different links in the chain are calculated as follows:

1. Retailer:

   Retailer buffer = maximum current consumption × stock replenishment cycle time × safety factor

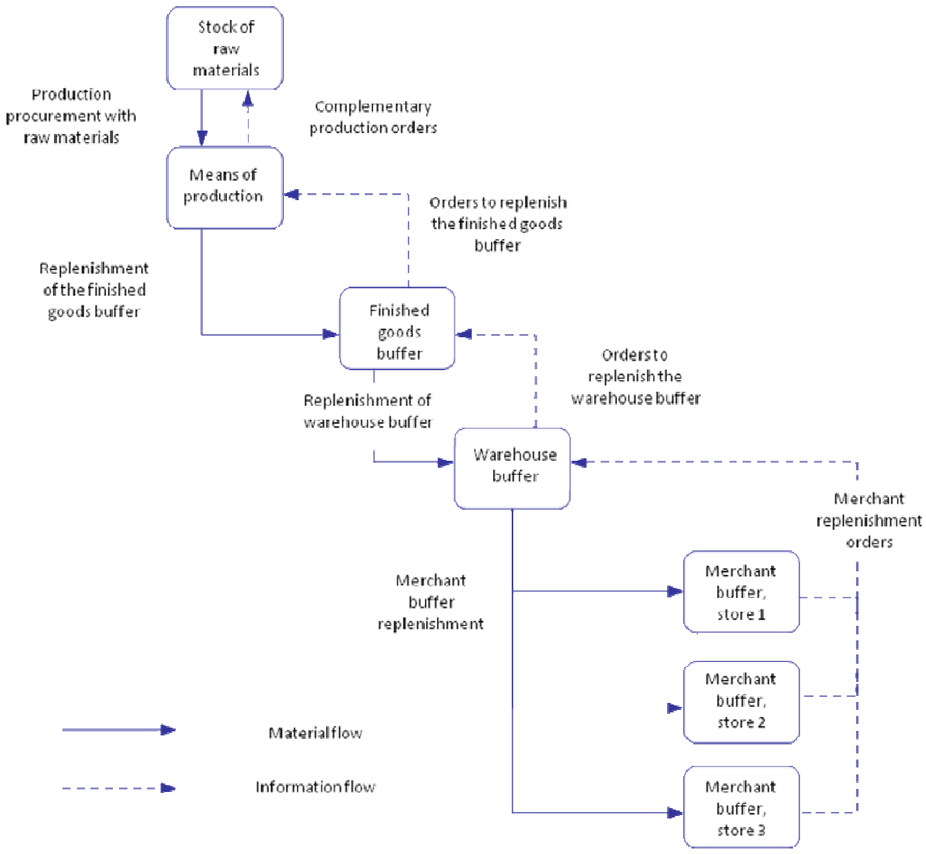
2. Finished goods warehouse:

   Warehouse buffer = maximum monthly consumption in all sales outlets in the region × time of stock replenishment from production × safety factor

3. Production:

   Production buffer ≈ maximum consumption within the entire chain × production frequency × safety factor

While monitoring buffer levels in the buffer management process an array of corrective actions is taken. The aim of these actions is to reduce or increase buffers, since the buffer level reflects the structure of consumption. As a result, they need ongoing monitoring.

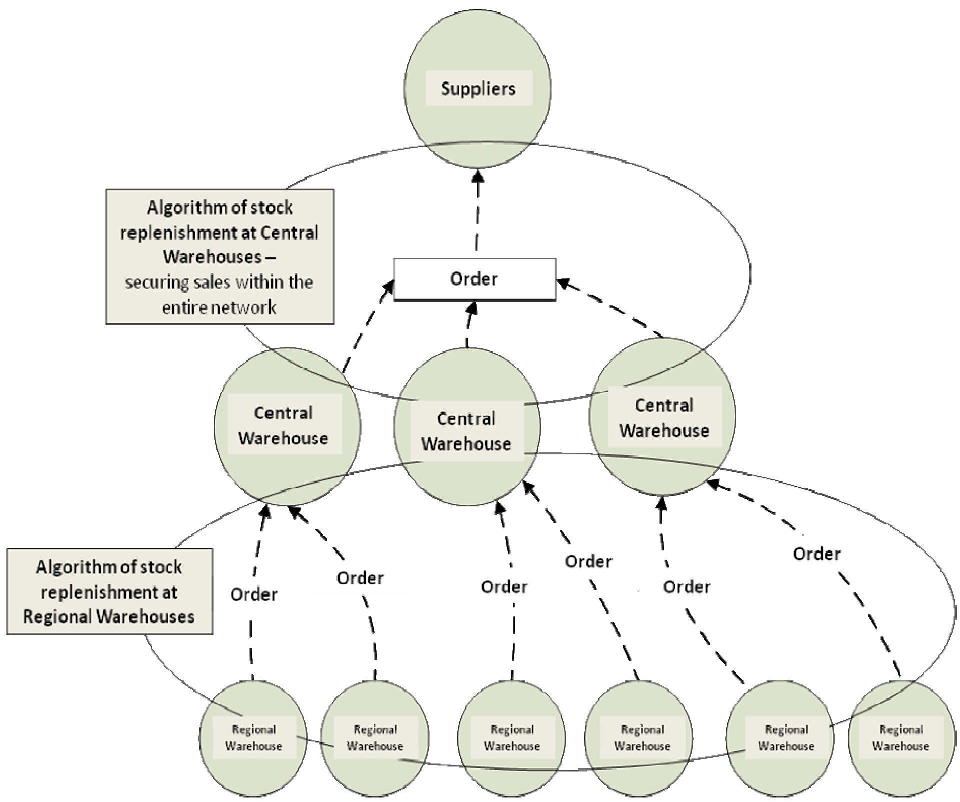


Source: own study based on Simatupang, Wright, Sridharan 2004

Fig. 1. Location of buffers within the supply chain
Rys. 1. Rozmieszczenie buforów wzdłuż łańcucha dostaw

SAMPLE TOC APPLICATION IN THE AREA OF STOCK MANAGEMENT IN THE PHARMACEUTICAL INDUSTRY

The process of streamlining the inventory replenishment model at various levels within the distribution network should begin with defining the network's functionalities. The target model of a distribution network for the analysed pharmaceutical Distributor assumes three Central Warehouses. The main role of stock stored in Central Warehouses is to secure sales throughout the entire distribution network. Therefore, it is vital to aggregate orders flowing in from different Companies to determine global needs of the network as a whole. All orders made by final customers (Pharmacies) aggregated at the level of Company Warehouses (Regional Warehouses) are directed to the Central Warehouse assigned to them. Orders placed with suppliers are generated on the basis of total product needs of all Central Warehouses. The operation diagram of the model distribution network in this aspect is shown in Fig. 2.



Source: M. Krueger, D. Doliński, P. Cyplik - unpublished ILiM materials.

Fig. 2. Diagram of operation of the model distribution network in place at the enterprise studied
Rys. 2. Idea funkcjonowania modelowej sieci dystrybucji w badanym przedsiębiorstwie

The basic change in the operation of the model distribution network is reorganisation of the system of deliveries to the final customers. The first delivery is to be completed at Central Warehouses, not - as it used to be - at Regional Warehouses. The solution assumes that the distribution hub (the place of main stock allocation in the distribution network) is in Central Warehouses. Company Warehouses will only perform cross-docking and transport to Pharmacies according to prearranged routes. The second and third deliveries to Pharmacies will consist of stock kept at Regional Warehouses.

Stock replenishment model at the proposed distribution network

The Company under analysis makes use of services provided by different suppliers, both Polish and foreign. A review of the role and operating conditions of Central Warehouses within the distribution network indicates that a reasonable solution is to analyse product ranges in an aggregate manner, for each supplier separately. This approach is related to trading terms and conditions offered by the supplier. One-off high-value orders placed with the supplier entitle the company to obtain higher discounts and make it possible to fulfill conditions stemming from the logistic minimum levels.

Traditional inventory replenishment models separately account for different assortment items, which is why they cannot be applied directly to the situation discussed in this study. Two traditional stock replenishment systems can be distinguished: one based on the so-called "ordering point" called informational level (ongoing review) and the other based on periodical review.

No such restrictions are present in the (s,c,S) model. The (s,c,S) model proposed by J.L. Balintfy assumes that materials are purchased the moment their stock level falls to the "s" level (equivalent to the alarm level in the traditional model based on "ordering point"). The quantity purchased will be equal to replenishment up to the level "S" (corresponding to the maximum stock level in the previously discussed model of ordering cycle). The moment free (disposable) stock of any assortment type achieves the "s" level (or drops below it), it is necessary to review other items classified in the same group and increase the order by those materials which are found to have fallen to the "c" level. For the stock replenishment system at Regional Warehouses, a modified TOC tool is proposed. Within the constraint-based framework, stock replenishment is based on stock buffer management in the appropriate link of the supply chain.

A combination of both inventory replenishment methods, i.e. the (s,c,S) model at the level of Central Warehouses and constraint-based model at Regional Warehouses makes up a hybrid solution for stock management in the distribution network of the enterprise analysed in this study.

Idea of stock buffer management in Regional Warehouses

The suggested stock replenishment option at Regional Warehouses consists of appropriate management of a specific stock buffer, taking into account prioritisation in product picking for delivery. Buffer size determines the maximum level of stock that should be kept at the Regional Warehouse. The volume of deliveries from the Central Warehouse to the Regional Warehouse is thus equivalent to the difference between buffer size and the level of free stock at the time of inspection. The notion of free stock refers to the level of stock in the analysed Regional Warehouse increased by stock in transit (orders unfulfilled by the Central Warehouse) reduced by product reservations for Pharmacies, if there are any.

The buffer size for various products in each of the Regional Warehouses which is capable of satisfying the overall demand of Pharmacies reported in their second and third order (taking into consideration the duration of the cycle of stock replenishment from the Central Warehouse) can be calculated using the formula below:

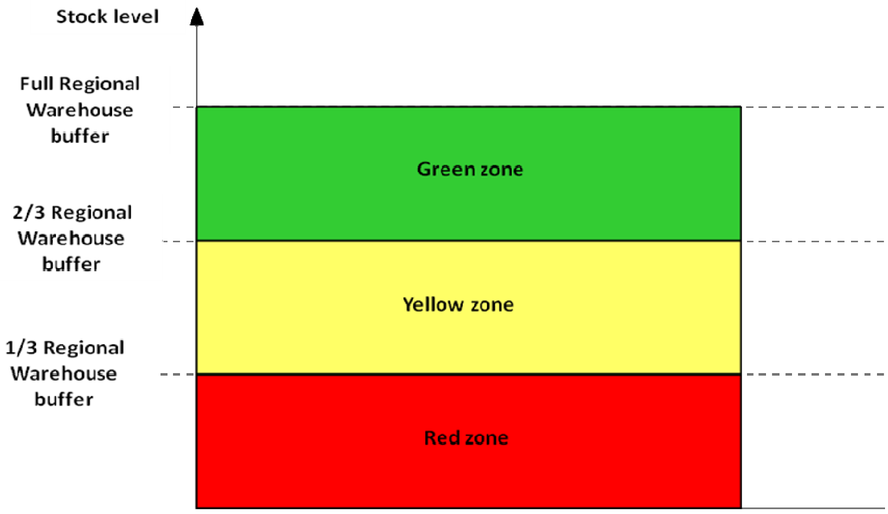
$$\text{Buffer } MR_i = P_{dmaxi} \times T \times \alpha$$

P_{dmaxi} - maximum daily demand noted for the i-th product during last month (resulting from the second and third order), applicable to standard regular sales, excluding promotional sales,

T - anticipated duration of the cycle of stock replenishment from the Central Warehouse,

α - safety factor (safeguarding against unpredictable events such as demand fluctuations).

As a rule, the buffer should be replenished from the stock available in the preceding supply chain link relatively frequently (as frequent deliveries mean low stocks). Fulfilment of the first delivery to Pharmacies from Central Warehouse stocks through cross-docking at Regional Warehouses makes it possible to replenish buffer stock in these warehouses throughout one day cycle. Due to limited capacity of means of transport and order-picking processes at Central Warehouses, it may turn out that some assortment items which should be replenished at the Regional Warehouse will only be brought with the next delivery. As a consequence, it is necessary to introduce the prioritisation of deliveries of different assortment items. This is where the other important function of specified buffers is clearly visible. The buffer size calculated for each product is divided into three equal zones: green, yellow and red, as shown in Fig. 3.



Source: M. Krueger, D. Doliński, P. Cyplik - unpublished ILiM materials.

Fig. 3. Buffer division into three zones
Rys. 3. Idea podziału bufora na trzy strefy

The highest priority in stock replenishment at Regional Warehouses is assigned to those assortment items for which the level of free stock at the time of inspection (every day at 6:00 p.m.) is within the red zone. A delivery of those assortment items must be provided to the Regional Warehouse the following morning. Medium priority is given for assortment items in the yellow zone and the lowest priority - for products in the green zone. Accordingly, daily order picking and loading of assortment items onto means of transport at the Central Warehouse takes place in the sequence listed below:

1. products for the first delivery to Pharmacies,
2. red-zone products,
3. yellow-zone products,
4. green-zone products,

On the one hand, the division of priorities makes it possible to satisfy current market demand (Pharmacies - first delivery) and make up critical stock in Regional Warehouses (red zone). On the other hand, this strategy enables full use of means of transport through the replenishment of stock in Regional Warehouses with products from the yellow and green zones.

SUMMARY

The article presents possibilities of using TOC in supply chain management. However, it needs to be emphasised that the Theory of Constraints has a broader range of applications and is a good foundation for developing new system management concepts. One of examples is the 3C concept which is a theory of management of material flow in the supply chain. Under the 3D concept, each supply chain should be analysed as a collection of links, also referred to as points of consumption, which are mutually interrelated. An example of practical implementation of TOC in stock management is the development of hybrid solutions combining TOC with other available methods. Currently, the company under study is in the process of introducing proposed modifications. The authors estimate that the implementation of the solution in the analysed pharmaceutical Company will contribute to reducing the level of operating stock in the distribution network by ca. 25%. On completion of the implementation process, it will be possible to measure other key parameters including NP, ROI and CF.

At present, authors of the article are researching the possibilities of using other tools of the TOC Thinking Process in supply chains. The main area of interest is the analysis of processes on the basis of the Current Reality Tree (CRT) and the Future Reality Tree (FRT), as well as the Transition Tree.

Application of the Theory of Constraints in the process of supply chain management has the potential to improve their operation in the circumstances of low demand predictability. TOC is also helpful in resolving problems associated with positioning and specification of stock volumes in different supply chains.

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IMPLEMENTACJA TEORII OGRANICZEŃ W OBSZARZE ZARZĄDZANIA ZAPASAMI W ŁAŃCUCHU DOSTAW - CASE STUDY

STRESZCZENIE. Theory of Constraints (TOC) jest filozofią zarządzania opracowaną przez dr Eliyahu M. Goldratta, która zakłada, że każdy system ma co najmniej jedno ograniczenie. Filozofia ta ma zastosowanie w różnych obszarach funkcjonalnych przedsiębiorstw począwszy od zarządzania przepływem produkcji, poprzez marketing, rachunkowość, zarządzanie projektem czy wreszcie jako narzędzie logicznego wnioskowania. Na łamach tego artykułu autorzy przedstawiają możliwość zastosowania teorii ograniczeń w łańcuchach dostaw, ze szczególnym uwzględnieniem zaimplementowania zasad zarządzania zapasami zgodnych z TOC w branży farmaceutycznej. Praktyczny przykład opisany przez Autorów jest ilustracją możliwości stworzenia hybrydowych rozwiązań łączących TOC z innymi metodami.

Słowa kluczowe: TOC, zarządzanie zapasami, modele uzupełniania zapasów.

DIE ANWENDUNG DER EINSCHRÄNKUNGSTHEORIE IM BEREICH DES BESTANDSMANAGEMENT IN DER LIEFERKETTE - FALLBEISPIEL

ZUSAMMENFASSUNG. Die Theorie der Einschränkungen (Theory of Constraints - TOC) ist eine Managementmethode entwickelt vom Dr. Eliyahu M. Goldratt. Sie setzt voraus, dass jedes System mindestens eine Einschränkung hat. Dieser Ansatz findet in verschiedenen Unternehmensbereichen Anwendung: im Produktionsfluss-Management, Marketing, Rechnungswesen, Projektmanagement. Diese Theorie dient auch als ein Werkzeug der logischen Schlussfolgerung. Die Autoren stellen die Möglichkeit der Anwendung der Theorie der Einschränkungen in den Lieferketten dar, mit besonderer Berücksichtigung der Anwendung der Regeln des Bestandsmanagement, die mit TOC übereinstimmen, in der Pharmabranche. Das von den Autoren beschriebene Praxisbeispiel zeigt die Möglichkeiten der Entwicklung von den Hybridelösungen, welche die TOC mit anderen Methoden verbinden.

Codewörter: TOC, Bestandsmanagement, Modelle der Bestandsergänzung.

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