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THEORY OF CONSTRAINTS AND ITS APPLICATION IN A SPECIFIC COMPANY

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Abstract

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This article analyses the possibilities of the practical utilization of Critical Chain Project Management methodology. Our study analyzed key processes related to the implementation and utilization of such a tool in a concrete company.
For this purpose an original program was created. The logic of this program is based on the fundamental principles of the CCPM methodology. The impetus for the design and creation of such a program stemmed from the almost non-existence of such a tool on the Czech market. The theoretical part of the article focuses concisely on the Theory of Constraints and Critical Chain principles, which the conceptual ideas of all algorithms included in the new program come from.
The system was used for two years and it enabled the processing of requests significantly faster than before. The evaluation of economical and practical benefits based on real project data demonstrates that after implementation of the Appello system and corresponding rules of usage, project managers completed more tasks in the first year than in the previous two years in which the CCPM was not applied and nearly 85% of planned requests were either on time or delayed up to 30 days in comparison with the amount of work from the preceding two years.
Currently, a significant number of project oriented companies are looking for competitive advantages which, allow for the mastering of the largest number of projects that have a delivery time specified within agreed time frames. The use of our system or similar ones designed according to CCMP rules fully ensures the fulfilment of such requirements.

Keywords: Theory of Constraints, Critical Chain Project Management, Critical Chain, Project management

INTRODUCTION

The main objectives of this manuscript are first to introduce a design of the project management system and constraint identification process in a real technological centre company using the Critical Chain Project Management (CCPM) methodology as well buffer management. Secondly the authors decided to evaluate the economic benefits after three years of the real usage of the designed system. The authors were facing several serious problems in a real project management environment and they decided to solve these problems through the application of CCPM in the real company. A lack of complete solutions on the market led to the development and application of the management system based on CCPM. The practical part introduces the analysis of the system application effects and results of the hypotheses after three years of test usage of the system. The authors setup four hypotheses:

H1: Shortening of the duration of the projects and increasing the ability to manage more multiple projects at the same time without the multitasking effect due to the designed system application will increase sales of own products and services by at least 25% in three years.

H2: The constraints identification process application will cause growing inventory to decrease.

H3: The designed system application will create an environment where the material component of inventory remains constant.

H4: The designed system application will cause the production-in-progress component of inventory to decrease annually by at least 10%.

To achieve both of the main objectives, the following methods were applied: Project Planning, Work Breakdown Structure (WBS), Network Chart of activities, CCMP, Project Management and evaluation, Buffer Management and constraint identification, Resource Workflow analysis, Conflict analysis and Five Focusing Steps. To get measurable economic results, the authors decided to use metrics such as Revenues from the sales of own production and services, TOC Inventory metric and Work In Progress.

MATERIALS AND METHODS

In 1979 a simple production scheduling software program called Optimized Production Timetables scheduling software was introduced. This technology efficiently generated master production schedules used to control mainly bottleneck locations. The Theory of Constraints (TOC) as a management philosophy evolved from these basic ideas into a suite of management tools and was applied to three related areas (WATSON *et al.*, 2007):

- Logistics and production;
- Problem solving thinking tools;
- Performance measurement.

The experiences of the first adopters led to the opinion that the application of TOC techniques will increase output, while decreasing both inventory and cycle time. These early findings have been validated by rigorous academic testing revealing that the performance of TOC techniques based manufacturing systems exceeds the performance of the systems using Manufacturing Resource Planning (MRP), Lean Manufacturing, Agile Manufacturing and Just-in-Time (JIT) (COOK, 1994; FOGARTY *et al.*, 1991; HOLT, 1999; RAMSAY *et al.*, 1990).

Theory of Constraints has been applied in hundreds of companies such as Boeing, General Motors and General Electric. TOC was also applicable in not-for-profit organizations such as NASA, United States Department of Defense and Israeli Air Force.

Eliahu Moshe Goldratt as one the co-founders of TOC introduced the principal tenets of TOC: within each system exists at least one constraint limiting the ability of the system to improve performance relative to its goal. Maximum utilization of that constraint should lead to maximum output from the system. Maximum utilization of other – non constraint – resources does not increase output but only creates unnecessary inventory. The early followers of TOC principles used Goldratt's publication, The Goal as their bible. TOC principles were easy to understand, but to put these principles into practice was extremely difficult despite the fact, that the novel, The Goal clearly outlined all the important heuristics and techniques which have become the foundation for TOC practice as well as the Five Focusing Steps (5FS) (WATSON *et al.*, 2007). This novel is taken as a golden cook book used to implement TOC. The 5FS can be taken as the core of the Drum-Buffer-Rope scheduling methodology (hereinafter referred to as DBR), where the drum is the main bottleneck in production setting the pace of production process, the rope is feedback used to release material at the beginning of the production and the buffer is the protective mechanism to prevent stopping of the bottleneck resource due to the lack of material.

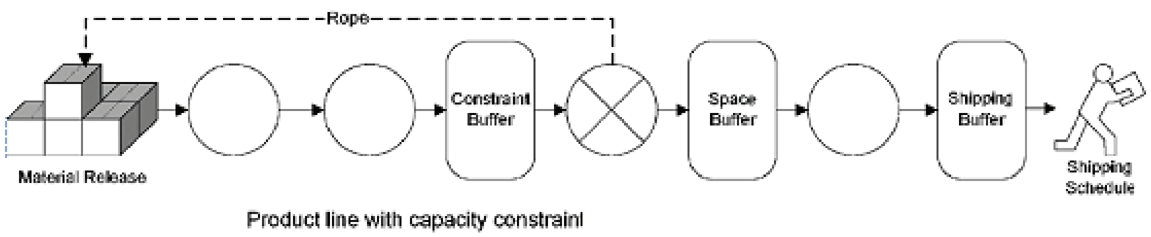
The aforementioned buffer may have either a physical character (material), which is in fact a time reserve when taken into consideration with the cycle time of the bottleneck or it can be understood simply as a time buffer if these so called capacity buffers are applied to project network schemas (Fig. 1)

E. M. Goldratt along with the work of others developed also a process-focused performance measurement system called Throughput Accounting (TA) (GOLDRATT, 1983). According to the TOC system the main goal is to make money now and in the future. To verify whether this goal is obtained, three global performance measures were used:

- Net Profit (NP);
- Return of Investment (ROI);
- Cash Flow (CF).

These traditional measures are useful in TOC for global performance measurements, but they are not suitable for the subsystem-level.

To bridge the gap between financial measurements and plant-level measurements, Goldratt and Coxx



1: *Typical Drum-Buffer-Rope configurations (WATSON et al., 2007)* introduced three plant-level performance measurements (GOLDRATT & COXX, 1991):

- Throughput (T);
- Inventory (I);
- Operating Expense (OE).

Until 1994, when Goldratt's novel It's Not Luck was published, TOC was perceived as a synonym for only Drum-Buffer-Rope. The novel It's Not Luck introduced TOC as a tool for solving much more complex and unstructured problems: the Thinking Processes tools (TP). The TP tools provide rigorous, systematic and logical means to solve problems related to management policies. The TP tools are comprised of two logical categories:

- Cause-effect logic;
- Condition logic.

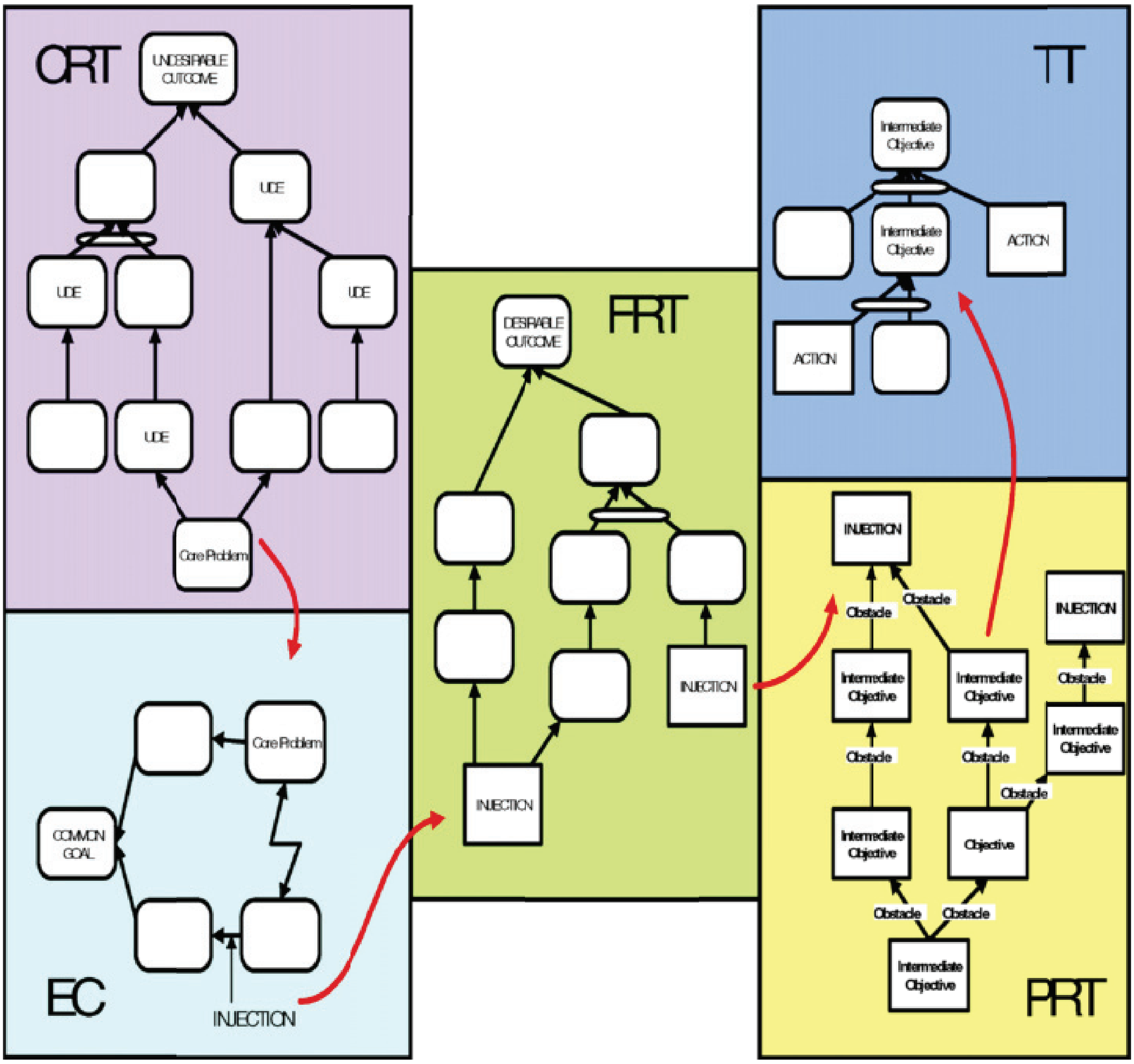
Cause-Effect logic is based on the current reality tree (CRT), future reality tree (FRT), and transition tree (TT).

Condition logic is based on the evaporating cloud (EC) and prerequisite tree (PRT).

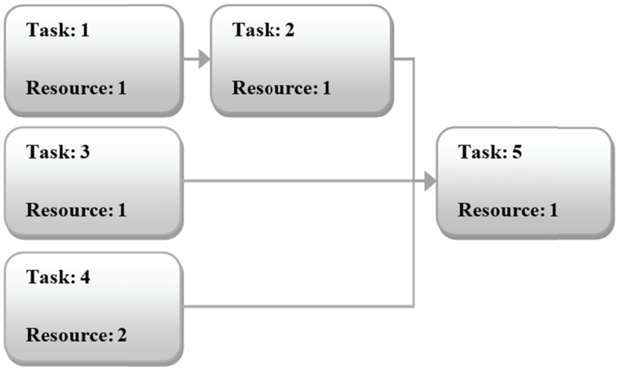
Application of TP tools begins with core problems identification through the CRT construction which consists of elements known as undesirable effects (UDE). From CRT evaporating cloud(s) can be created, which can facilitate the core problem identification process by seeking core conflicts or answers to the questions that clarify the situation.

EC should discover hidden assumptions, which are invalid or can be invalidated by future actions called injections. These injections are the basic step to successful problem resolution.

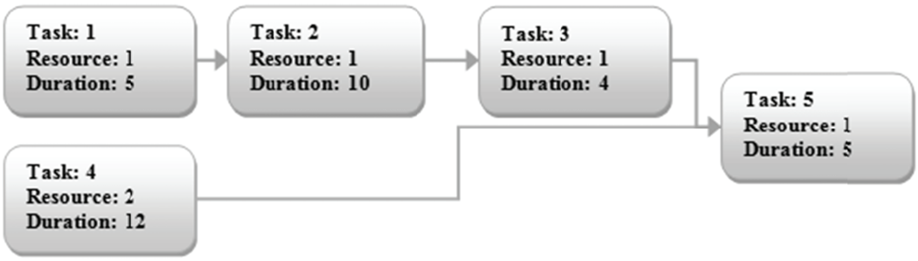
The solution is tested by the means of the FRT to ensure that no negative results will arise from the resolution application. After the validation of the solution, it becomes an objective of PRT to find out what must be achieved (prerequisites) in order for the successful application of the solution. All identified objectives and injections are utilized as inputs into the TT to develop a specific implementation plan as is shown in Fig. 2.



2: *The TOC thinking process application tools (WATSON et al., 2007)*



3: *Critical path illustration (LINHART, 2013)*



4: *Critical chain illustration (LINHART, 2013)*

TP tools have been successfully applied many times and they are mutually supportive with associated methods such as lean management, quality management, and process reengineering. Integrated tools may just help to understand better the problem and to improve solution development.

Bearing in mind a possibility to use TOC in Project Management the Chain Project Management (CCPM) was introduced in 1990 at the International Jonah Conference, but this concept remained unstudied until Goldratt published the novel, Critical Chain in 1997. CCPM is an effective method of project management; it is an application of the 5FS to project management using buffers to manage the projects and to protect task fulfilment time fluctuation. CCPM is similar to critical path project management, but CCPM employs buffers, eliminates resource conflicts and assigns activity duration

The CCPM method uses three fundamental features distinguishing it from Critical Path Management:

- Critical chain eliminating conflicts;
- Takes into consideration capacities of the resources and not only technological dependencies;
- Relay race principal;
- Buffer management and monitoring.

Standard critical path method identifies the longest path of activities in a project network. The path with longest overall duration is critical for the project and is illustrated in Fig. 3.

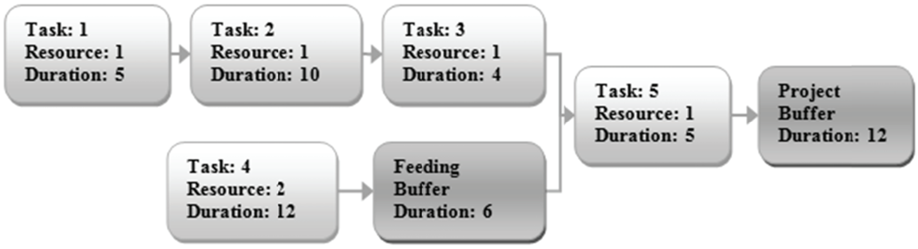
Critical chain methodology eliminates resource conflicts. When one resource works on two tasks together, the duration of activities will be longer due to the multitasking effect. Of course, if the duration time is planned with no time slack, the conflict task prolongs the duration of the project, even if the resource fulfils one task after another. The critical chain algorithm solves conflict tasks in such a way, that all tasks assigned to critical resource (R1) are placed into the critical chain structure as is shown in Fig. 4.

In order to show the main advantages of using CCPM instead of CPM we will refer to several fundamental differences throughout our manuscript.

Firstly, CPM uses percentage estimation expression for task fulfilment, which does not reflect problems and obstacles which can arise during project realization. The feedback is not alarming. On the other hand CCPM uses estimation task duration for task fulfilment. The management of the project using this metric is much easier.

When planning the project using CPM, the time slack is added to the task duration time. The ending date of the last project task is the final deadline of the whole project. On the other hand, the CCPM plans tasks with ideal task times with no slacks added to the duration of each task. A suitable analogy to this principle can be found in that of a relay race. Every task must be finished as quickly as possible.

The ideal term of such a chain with no slacks cannot be assumed as a real term of the whole project. There are always too many risks and natural delays against which it is necessary to protect the project. To protect, control and monitor the project, CCPM introduces time buffers. A project buffer is placed at the end of the project network. Shorter feeding buffers protecting the secondary (non-



5: *Critical chain with time buffers (LINHART, 2013)*

I: *Practical and economic consequences (LINHART, 2013)*

Practical consequences	Economic consequences
● Regular delay of projects of more than two months	● Smaller annual volume of orders. ● Loss of orders due to customer dissatisfaction. ● Higher costs associated with the effort to catch up.
● Lack of data for planning due to the inability to evaluate projects and estimate their real duration	● Unreal cash flow planning. ● Ineffective capacity utilization. ● Unnecessary inventory creation or vice versa, late orders for material.
● Incorrect constraints identification	● Managers and interested resources wasted time by eliminating problems that were not causing delays

critical) chains are placed at the end of the secondary chains before feeding into the critical chain. The illustration of the 50% time buffer applied to the project is illustrated in Fig. 5.

The second important difference of CCPM and the CPM is that critical path logic assumes all project tasks will start as soon as possible. At the project startup, the project manager must concentrate on starting all tasks at the same time. The start time of the secondary project chain is determined by the feeding buffer. Secondary chains can start later as they are still protected with both feeding and project buffers.

In contrast, the CCPM schedules all projects tasks in time. Buffer management is a method to monitor and control the whole project by monitoring only project buffer penetration.

As a result, a project manager can see the project fulfilment at any point in time and then react properly in order to eliminate all existing threats through the monitoring of so called, project traffic lights.

RESULTS

Results – Management Problem Specification

What conditions led to the main decision to create a new project management system based on the TOC and CCPM?

Consider a company with know-how in the area of Radiation Protection and the Monitoring of Radioactive Waste management. Its mission is the realization of complex, customized turnkey solutions comprised primarily of independently developed devices and software systems. Large projects are managed including activities such as purchase, research and development of the measuring instruments, detectors or other electrical equipment, and the purchase, research, development and installation of the software systems.

First came the economic downturn and later (in 2009) the company encountered limits in production and development duration. Sales of the products were greater than the ability of the production.

The production and development section with 32 workers and engineers was working simultaneously on more than 90 multiple projects; the approximate average demanded project duration was three months. Some projects could take several weeks; some could take up to two years. The practical and economic consequences are described below in the Tab. I.

These consequences led to the decision of top management to implement the Multi Project Management System from January 2009.

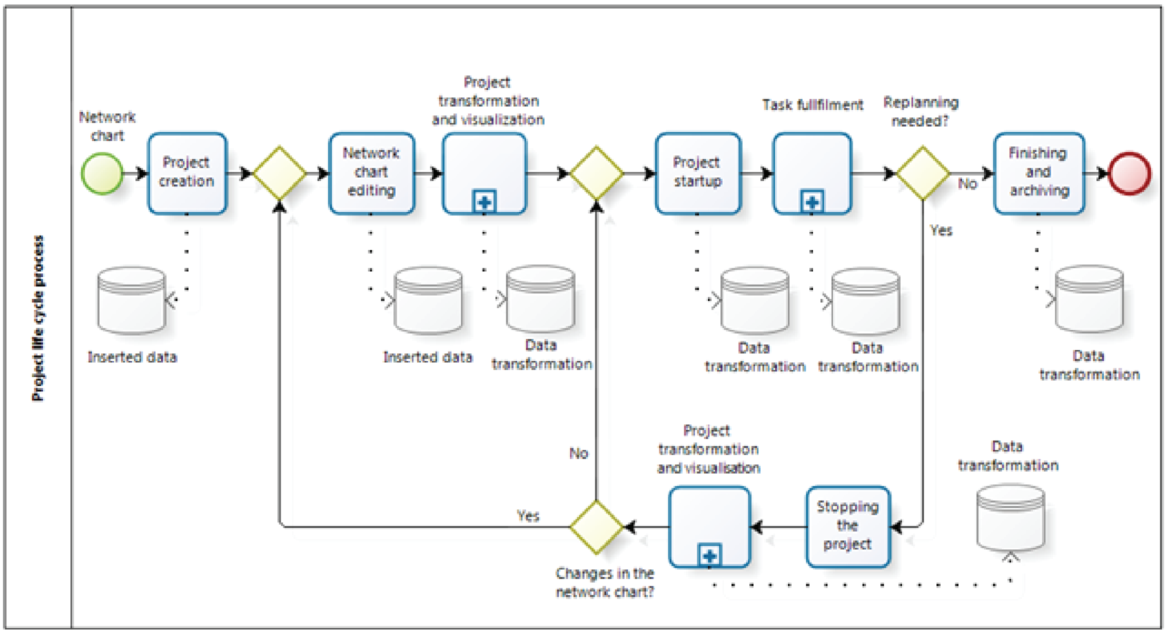
Results – Research & Design of the Program

The first step necessary to create a system was a design of system structure and processes. The system was written in PHP (*Hypertext Preprocessor*) using the SQL (*Structured Query Language*) relational database.

In the beginning, of the system development had to be designed for the life cycle process of the project which is illustrated in Fig. 6. This process contains the basic spirit of the whole system.

The first step of the life cycle process is the simple creation of the project; technically the insertion of one row into the table of projects in the database. Another step is the network chart editing.

The project network chart is a logical sequence of tasks as listed in the Tab. II.



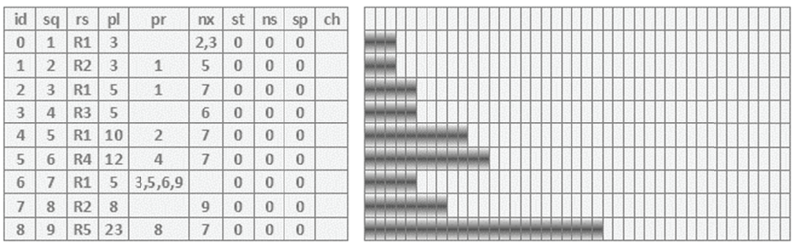
6: *Model of the project life cycle process (LINHART, 2013)*

II: *Table of project tasks (LINHART, 2013)*

ID	Sequence	Description	Previous
0	1	Task 1	
1	2	Task 2	1
2	3	Task 3	
3	4	Task 4	
4	5	Task 5	2,3,4

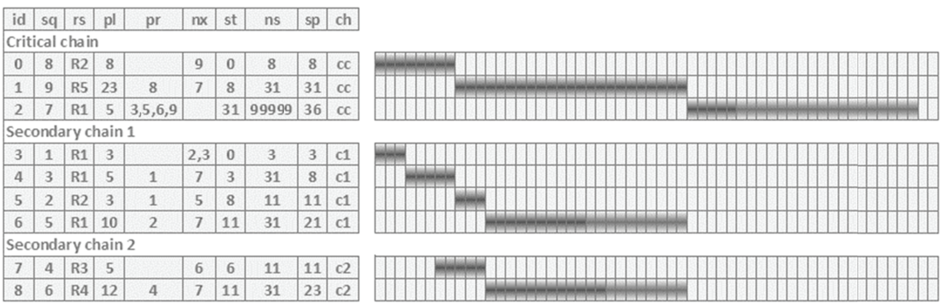
After the project is created and the network chart is edited, project transformation and visualization sub-process can be run. This is one of the most complicated processes – to create the final project suitable for CCPM from a simple list of tasks, with buffers and timing of the tasks without any conflict of resources as is shown through the models in Fig. 7 and Fig. 8.

Project startup is an operation that converts the project matrix into real time. After this is done, the tasks are sent to the workflow system which is enabled for all users of the system. During the life cycle of the project, the tasks are fulfilled by the users. Every user is a resource or a person responsible for any external resource and its tasks.



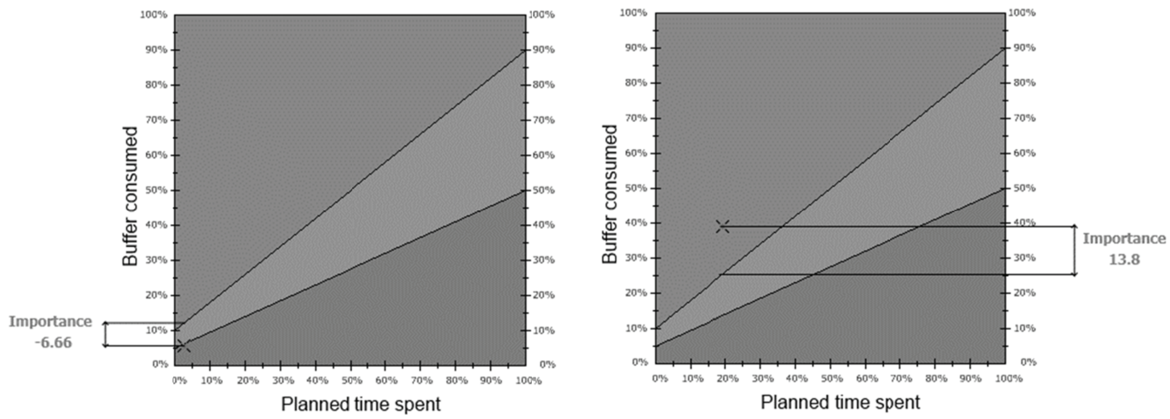
id	sq	rs	pl	pr	nx	st	ns	sp	ch
0	1	R1	3		2,3	0	0	0	
1	2	R2	3	1	5	0	0	0	
2	3	R1	5	1	7	0	0	0	
3	4	R3	5		6	0	0	0	
4	5	R1	10	2	7	0	0	0	
5	6	R4	12	4	7	0	0	0	
6	7	R1	5	3,5,6,9		0	0	0	
7	8	R2	8		9	0	0	0	
8	9	R5	23	8	7	0	0	0	

7: *Model of the default project matrix (LINHART, 2013)*



id	sq	rs	pl	pr	nx	st	ns	sp	ch
Critical chain									
0	8	R2	8		9	0	8	8	cc
1	9	R5	23	8	7	8	31	31	cc
2	7	R1	5	3,5,6,9		31	99999	36	cc
Secondary chain 1									
3	1	R1	3		2,3	0	3	3	c1
4	3	R1	5	1	7	3	31	8	c1
5	2	R2	3	1	5	8	11	11	c1
6	5	R1	10	2	7	11	31	21	c1
Secondary chain 2									
7	4	R3	5		6	6	11	11	c2
8	6	R4	12	4	7	11	31	23	c2

8: *Model of the final state of the project matrix (LINHART, 2013)*



9: *Signalling chart and importance of the model project in various stages (LINHART, 2013)*

To manage the project, two metrics are measured during the project:

- Buffer consumption;
- Importance.

Buffer consumption metric is expressed as a percentage, 100% means that the buffer is completely consumed and any day of delay means a delay of the project.

Importance metric is expressed as the difference between a status point and a point, which is part of the alarm function at the time. The alarm function indicates the upper signaling line. The guiding principle of this metric lies in the following fact: Every day of buffer consumption is much more dangerous at the beginning of the project than at the end of the project. Buffer exists to protect the project as a whole.

The more tasks in the critical chain are completed, the more of the buffer can be afforded to consume without danger. The importance and its meaning is illustrated by the charts in Fig. 9. Warning and alarm functions (which are creating yellow and red areas) are fully adjustable by user.

Both metrics are monitored and compared online during the project life cycle with the values of other projects turning the buffer management into a powerful tool. Each task is also monitored and can therefore immediately reveal any problematic tasks.

All projects can be joined to the tasks as sub-projects. All stopping and transformation operations of the master project are transferred to the unlimited number of all sub-projects using a special "unlimited" algorithm. All sub-projects are synchronized with the master project.

Conflict identification system identifies all current tasks of the project which are in conflict with any other existing task. The conflict table shows all collisions and their priority in the workflow of the resource.

Results – Program Implementation

The tasks needed to fully deploy the system grouped almost naturally into three phases:

I. Technical phase;
II. Training phase;
III. Involvement phase.

Technical phase consisted of the installation and initial setup of the system. Preparation of server and domain was a routine task for IT department. In March 2009, the technical phase was finished and all projects were managed in the Appello Multi Project Management system.

Training phase consisted of the education of team leaders and engineers in TOC and CCPM principles and of the education of all users on how to operate the system.

If the technical phase was a matter of hours and the training phase was a matter of days, the **involvement phase** was a matter of months and years. Experience with the system implementation showed, that there is a very big difference between system operation skills and real involvement of the users. As it is usual in the implementation of new work patterns, the significant resistance to change showed.

DISCUSSION

We have searched relevant information resources in order to articulate the current status of CCPM utilization in practice. The main aim of this paper was to publish the results of long term practical application of our unique software package based on the critical chain algorithm. The practical use of CCPM in our case is limited by several important factors.

The first one is the low availability of CCPM applications on our local market. We discovered, that on the Czech market, there are only a limited number of companies offering software products based on critical chain principles, where these applications are used in project management. Most of these sophisticated software packages originate from abroad. We can cite e.g. Concerto, Lynx from A-Dato, ProChain as an Add-On for MS Project and Sciforma 6.0 as products within this offering. Most of them are not localized for the Czech language. Some Czech ERP providers have created add-ons for these complex systems in order to at least incorporate buffer management logic.

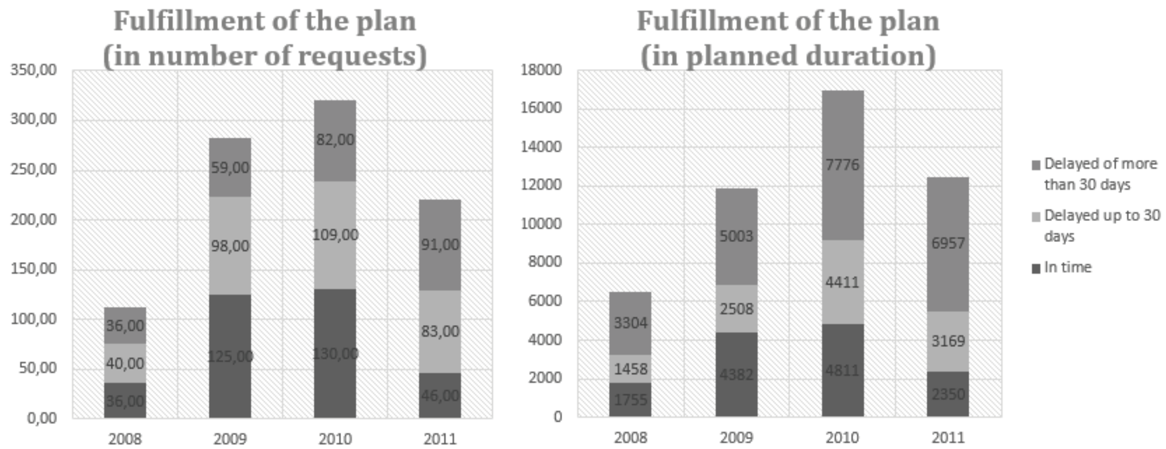
The second important factor has managerial aspects. Some of the prophetic managers, who have decided to implement CCPM methods and tools struggle to find invaluable experiences from similar projects, they are afraid to lose control over details and moreover they have problems to avoid the enrooted fears of the negative influence of adjacent project activities and problems resulting from a lack of resource capacities.

CONCLUSION

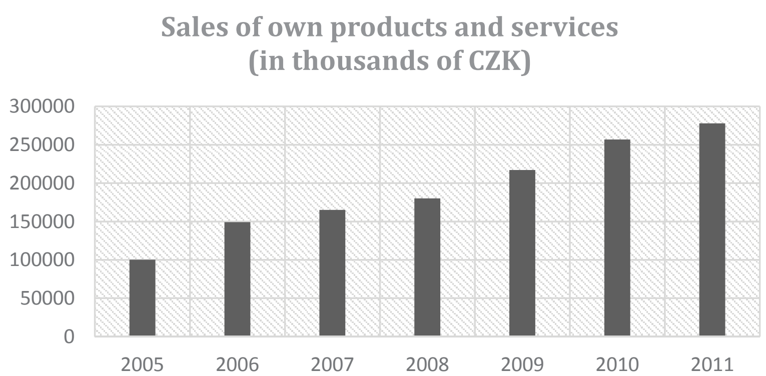
The fulfillment of requests ration related to the number of requested tasks and the amount of work in the planned durations in days is shown in Fig. 10. The Appello system enabled the processing of much more requests in much better times. According to the first chart, in 2009 and 2010 more tasks were completed in time than the whole number of tasks in 2008. According to the more objective second chart, even in 2011, nearly 85% of planned requests were in time or delayed up to 30 days when compared with the amount of work in 2008. And more than twice of other requests were fulfilled at a delay.

The number of fulfilled requests directly affected the sales of own products and services. Without being processed and manufactured, products and services cannot be sold. The development of the sale of own products and services is shown in Fig. 11. Sales of own products and services in 2008 were 180 million CZK, in 2012 they were 278 million CZK, this represents an improvement of 54%.

Problems with planning caused inventory accumulation in the company's warehouse. In 2008 inventory was 82 million CZK, in 2009 the state increased further (Appello was implemented, but the effect of constraint identification and their removal was delayed), but from 2010-2011 it decreased to the value of 60 million CZK in. This represents a decrease of 27%. Purchase planning was influenced by Appello by finding constraints in current projects as shown in Fig. 12.



10: *Fulfilment of the plan (LINHART, 2013)*

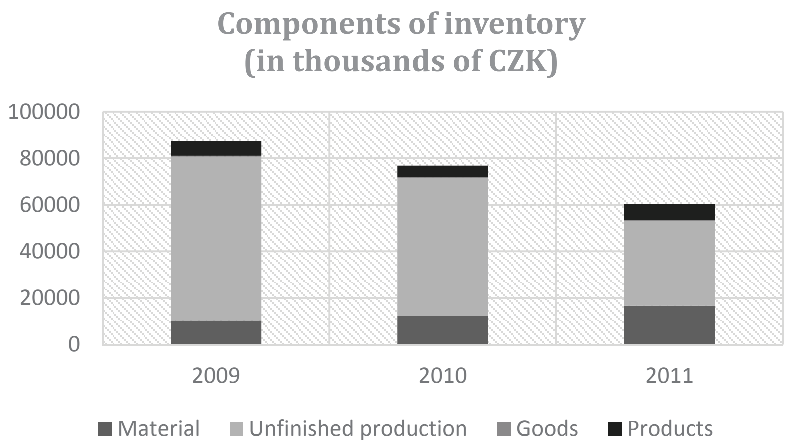


11: *Fulfilment of the plan (LINHART, 2013)*

SUMMARY

The effort led to the reduction of the production-in-progress inventory (called unfinished production) through the correct timing of the orders and by converting ineffective material inventory into critical material inventory (critical material had to be identified during the repeated production as constraints in ordering tasks in projects). Despite the effort not to increase the material component, it has been increased by 6 million CZK, but the unfinished production component has been reduced from 70 million CZK to 36 million CZK, this represents a reduction of 49%. Annual average reduction is by 27%.

During the active use of our system, Appello, the subject company did not introduce any new processes which bear consequences on the reduction of inventory supply. Moreover, the level of work-in-process as well as the level of raw material inventory during this time, was influenced only by the technological centre of the subject company, which used Appello. In particular, work-in-process was significantly reduced as a result of the shorter lead times despite the fact that total production volume increased. The level of raw material inventory was under better control due to the identification of more transparent constraint identification enabled through the usage of Appello. This fact allowed for the better estimation of placement locations for safety stock in order to protect throughput on these constraints and thus avoid an unwanted raw material inventory increase. On the other hand, due to the increase of production capacities some parts of production where considered from time to time as make-to-stock and thus the inventory of finished goods slightly increased. The principal decision of production type ratio make-to-stock/make-to-order was the responsibility of sales department of the company. The main interest of this department was to increase throughput and at the same time, decrease inventory value. Based on our findings, the influence of finished goods inventory to total inventory value was far less than the potential influence of the other two inventory segments, meaning work-in-process and raw material inventory. Based on the above mentioned results all stated hypothesis were validated.



12: *Inventory states (LINHART, 2013)*

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