Is Critical Chain Project Management Really a Novel Technique?

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Abstract. *In the growing discipline of Project Management (PM), the techniques used for project planning mainly include methods developed at dawn of modern PM back in 1950's. Therefore, they are influenced by Operational Research and are founded on Program Evaluation and Review Technique (PERT) or on Critical Path Method (CPM).To fulfil the growing requests for better planning of large projects, practitioners had tried to develop simple and working models, which has resulted in emergence of new project planning techniques. One of the most cited techniques in the last several years is the Critical Chain Project Management (CCPM).The aim of this work is to give an overview of the CCPM technique, with an assessment of differences to CPM. It shall highlight the benefits and shortcomings that CCPM has brought to the PM community.*

Keywords. Project Management, Scheduling, Project Planning, Critical Path, Critical Chain, Theory of Constraints

1 Introduction

Project Management is one of the fastest growing disciplines which started its development in the second half of the 20th century mainly from the technical environment and it has become a multidisciplinary field of study [6], [15]. Technical roots are mainly visible in the project scheduling which includes processes important for activity sequencing and finishing project on time [10].

Classical project scheduling techniques include network diagrams, Gantt charts and especially Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM) [6], [9], [10], [17]. These methods are heavily used within Project Management community, even though growing criticism can be noticed, stating that these techniques can fulfil their purpose only when applied to simple projects and project plans [9], [13]. Recent research on software tools used in ICT projects in Croatia showed that the most used features are exactly PERT/CPM and Gantt chart which are used together for project planning by more than 90% of respondents [13].

But, there is a visible correlation in growing criticism of the before mentioned techniques and a growing number of new project scheduling techniques [9]. Criticism is mainly based on the statistics on projects which failed in completing on time, and the new techniques try to increase the probability for successful project completion. One of such techniques is the Critical Chain Method, defined by PMI as "…schedule network analysis technique that modifies the project schedule to account for limited resources. Critical Chain combines deterministic and probabilistic approaches." [10].

Even though the current trend of number of articles on Critical Chain Method is slightly decreasing, there are still articles on the topic in recent journals which document successful application of Critical Chain Method [2], [3], [5], [7], [11], [11] [12], [13], [16][8]. But, critiques emphasize the fact that this technique is not such a revolutionary invention, and that it merely combines well known facts which were historically developed and influenced by Operational Research [2], [3], [5], [12], [16].

2 Network diagramming

Activities together with their durations and logical sequence represent main elements for project planning and scheduling [10], [17]. Network diagrams provide logical activity sequence and especially the earliest possible project finish date which is defined by the longest sequence of activities through the network diagram, called critical path [6], [17].

Critical path can be calculated by knowing late and early schedule defined for every single activity with early start, early finish, late start and late finish dates. Therefore, critical path could be defined as the sequence of activities which must complete in planned time in order for project to finish on time, and any delay in a critical path activity will result in project delay, by the very same amount of delay [17].

Different but very similar definitions of critical path could be found, as that it is the shortest possible task sequence which leads to project completion [1] or, as defined by PMI "Generally, but not always, the sequence of schedule activities that determines the duration of the project. Generally, it is the longest path through the project. However, a critical path can end, as an example, on a schedule milestone that is in the middle of the project schedule and that has a finish-no-later-than imposed date schedule constraint." [10]

It is not always an easy task to define critical path. One way of identifying it could be by calculating all possible paths through the network diagram and selecting the longest one as the critical path, but for larger projects this is not practical. Therefore, it is easier to use slack or float, which is defined as a delay which can be allowed for activity start without endangering project completion time. Using slack, critical path is defined as an activity sequence that has zero slack [17]. Sometimes, a negative slack can occur, as a result of unrealistically set completion time, and slack decrease could be used as an early warning controlling mechanism [6].

The last step in activity network planning is the network analysis and re-planning in order to shorten total project completion time by analysing activity interdependencies and resource levelling or reallocation, which can result in a new critical path [6], [10], [17].

3 Theory of Constraints

Theory of Constraints (TOC) was introduced by Dr. Eliyahu M. Goldratt in 1984 in his novel The Goal [8], [17]. TOC is based on the manufacturing system analysis, with the main idea that every system must have a constraint, and that system output is limited by exactly one constraint at a time [8]. If the system goal is known, Goldratt suggested the following steps (Fig. 1) to continuous improvement [5], [8]:

- Identify the system's constraint.
    - By definition, every system has exactly one constraint at a time, which has to be identified correctly in order to direct all changes to improvement; changes directed to other parts of the system would not result in system improvements.
    - Answer to question "What to change?"
- Decide how to exploit the system's constraint.
    - To achieve the best results, it is important to decide how to improve (exploit) the constraint.
    - Answer to question "What to change to?"
- Subordinate everything else to the above decision.
    - When it is decided what to change and what to change to, everything else must be subordinated to achieve the wanted goal.
    - Idea on "How to cause the change?"
- Elevate the system's constraint.
    - Very often the most difficult step, as it is needed to implement change in system and people behaviour.
    - Implementation of "How to cause the change?"
- If a new constraint appears, start over.
    - By eliminating one constraint, very often another one will become visible, which had to be removed by the very same procedure.

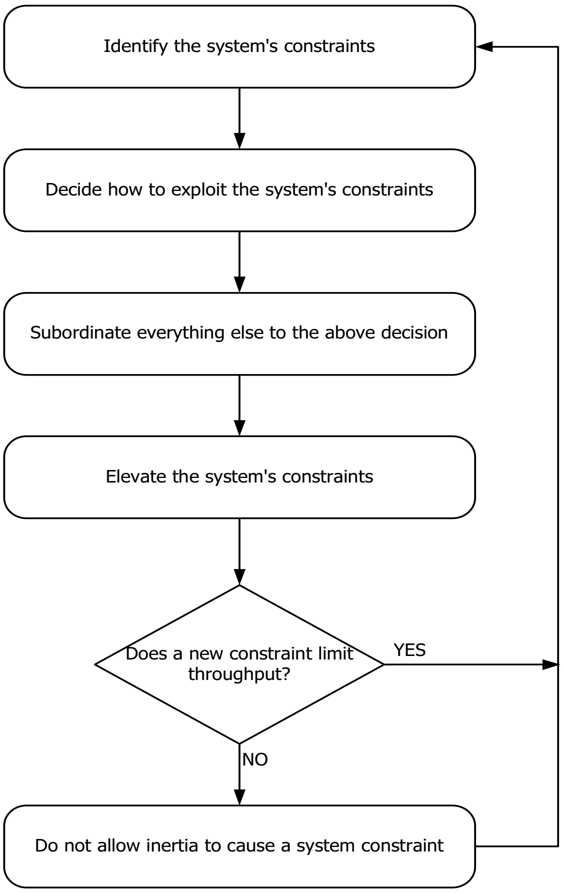

Figure 1. Five steps to continuous improvement

These steps are part of the process which Goldratt tends to call the Thinking Process, and more details can be found in [8].

4 Critical Chain Project Management

Application to the field of Project Management started in the late 1990's, even though the basis of TOC was set up in 1984 [12], [17]. The term Critical Chain Method, and the connected term Critical Chain Project Management (CCPM) (sometimes called Critical Chain Scheduling/Buffer Management – CCS/BM) then became popular, which could be seen from the number of published papers in the period between 1998 and 2002 [2], [3].

CCPM foundations find justification in addition to TOC and System Thinking in activity duration variations and in rules of statistical distribution [7], [8], [17]. Variation of activity durations can have common cause, and such variation is built in the system and cannot be influenced. In addition, there can appear special cause variation, specific for an activity or part of the system. Common cause variation cannot be influenced, but it can be exploited using statistical rules, while special cause variation can be mitigated or avoided with appropriate risk management [17].

CCPM uses statistical distribution theory as well, stating that the variance of a sum is the square root of the sum of variances of each of the components in the sum, and the square root of the sum of squares is less than the sum itself (1) [7], [17]. Central limit theorem in addition claims that, the higher the number of samples, the distribution is more likely to get closer to normal distribution. Later discussion will show application of theories in practice.

$$\sigma_{\Sigma} = \sqrt{\sigma_1^2 + \sigma_2^2 + ... + \sigma_n^2} \quad (1)$$

4.1 Behavioural aspects

By using Goldratt definitions and process, project management can be defined as a system whose goal is a successful delivery of project results [8]. The most important factors influencing and defining project success are time, cost and scope (correlated by so called Iron triangle – Fig. 2), and generally speaking customer satisfaction [15]. Considering project planning, and especially project scheduling as mainly time management, and having in mind that time influences other factors as well, project goal can be defined as project completion on time, i.e. in the shortest possible time.

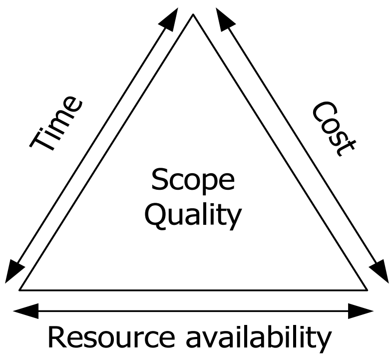

Figure 2. Iron triangle

Classical project scheduling techniques (CPM, PERT) use activity duration estimation, and do not challenge that estimation, but take it as relevant and solid value.

For more detailed evaluation of activity duration estimation it is essential to analyse factors influencing estimation and factors influencing activity duration itself. These factors result in project delay compared to original project plan, but also in a delay of a certain activity [8]. Additionally, it can be considered in the terms of CCPM and its underlying theories that main reasons for project delay are failure to pass positive common cause variation, meaning that early task finish has not been exploited; multitasking; loss of focus on key activities and project delay because of delay in a path merging to the critical path [7].

Typical behaviour of the estimator is trying to include all uncertainties in the estimation, and such estimated time has a really small probability for not completing on time, but at the same time very large redundancy. The problem very often occurs in the activity execution phase as majority of activities finish late compared to project plan.

Estimation of activity durations is often influenced by different factors contributing to low risk estimation, i.e. probability of finishing on time is very often over 80 % (up to 95%) [8]. Every estimate includes contingency (buffer) due to uncertainty which contributes to longer activity duration estimation.

Multitasking and so called Student Syndrome are the most common reasons for project delays. Multitasking results in a delay of every parallel activity, while Student Syndrome behaviour indicates that actual work on an activity will start later than planned because of human nature and the tendency to underestimate actual time needed for activity, so actual work on activity will start too late to be finished on time [5], [7], [8], [11], [12].

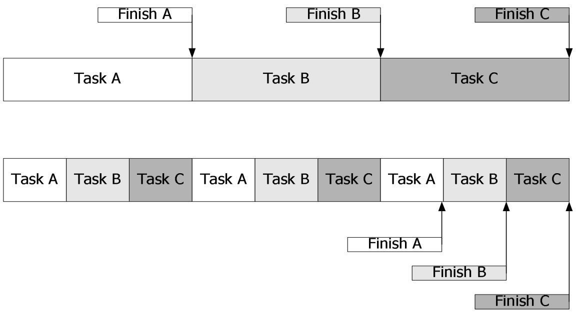

Figure 3. Multitasking of project activities

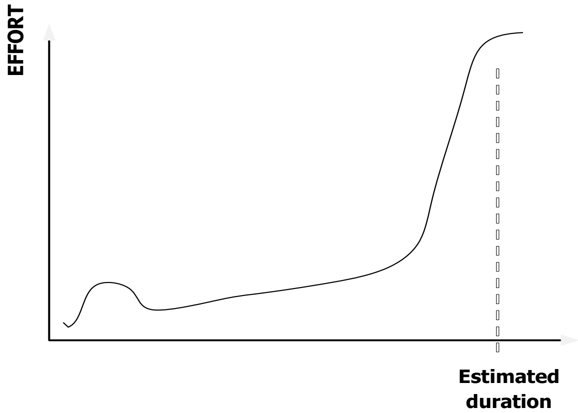

Figure 4. Student Syndrome

It can be said that a deviation exists between estimated activity duration and actual execution.

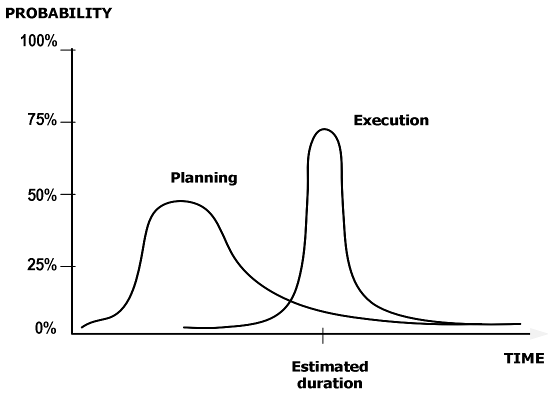

Figure 5. Estimated duration and actual duration of project activities

In other words, CCPM tries to avoid project delay caused by Parkinson's Law (work will expand to fill the time allotted to it) while trying to protect from Murphy's Law (uncertainty) [2].

4.2 Critical chain

Critical chain is defined as the longest activity path through the project, considering both activity interdependence and resource constraints [5], [8], [12], [17]. Such a defined path constrains the total project duration and in the terms of Goldratt's definitions can be considered as a system (project) constraint.

Critical path is a special case of critical chain with unlimited resources, as it uses only activity dependence [8].

Having in mind critical chain as constraint, it is needed to decide how to exploit that constraint, i.e. how to shorten the planned time as well as the actual execution time [8]. It can be possibly done by exploiting the estimated activity duration, statistical common cause variation or resource availability [8].

By using the statistical distribution theory and moving the contingency (buffer) from the tasks and adding it only at the end of the path, the project plan is protected from uncertainty caused by common cause variation. It is accumulating uncertainty contained in buffers from each task into one buffer whose size is smaller then the sum of all the task buffers because of (1).

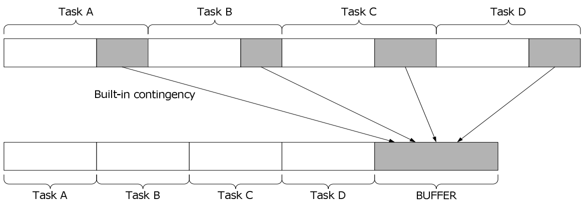

Figure 6. Project buffer

Almost every project is comprised from several possible project paths, but usually only one is by CPM definition critical path and all other paths feed the critical path. Therefore, critical chain logic must be applied to feeding paths as well.

Because of the very nature of critical chain, resources cannot be allocated to activity with explicitly defined start and finish times (activity duration is not deterministically set) and therefore resource buffers have to be applied, as a flag indicating when a resource will be needed, in order to enhance resource utilization and prevent project delays due to resource unavailability.

4.3 Buffers and buffer management

As described in the previous chapter, buffer is a segment of time placed at the end of tasks sequence in order to protect schedule of those tasks [17]. Buffer is dependant on total duration of tasks at which end it is attached and its size is determined using already described statistical distribution laws. It is placed in the project schedule as a standalone task without resources allocated to it [5], [8], [17].

There are several different buffer types, but the three mainly used include: project buffer (time segment added to the end of a critical chain for protecting project schedule), feeding buffer (time segment added to the end of a feeding chain) and resource buffer (flag, not a time segment, to point to a resource when it is needed) [8], [12], [17].

Several other buffers relate to a Multi-project environment, such as capacity constrained buffer (buffer placed between projects to ensure the projects sequence), cost buffer (total project cost protection) and drum buffer (capacity of a single resource allocated to several projects) [17].

When the initial project plan has been defined, the project manager using CPM/PERT is mainly concerned to ensure timely execution of critical path activities and completion on the planned finish times. By using CCPM, focus is transferred from finish times to project buffers and the project manager manages only the buffer [17]. Project manager checks project buffer in short time intervals and according to buffer usage triggers some action [7], [17].

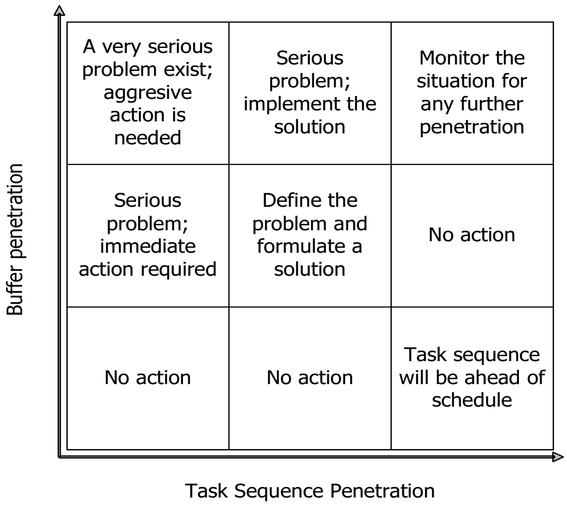

Figure 7. Buffer penetration and action decisions

It is possible to achieve a similar result by using graphical representation, fever chart, which shows tendency in buffer usage and decisions are based on current position in the chart. Higher attention is paid if the position is within yellow area of the chart, but actions are triggered if positioning in red. Balance between areas is set arbitrary and it can differ for different critical chains or for different projects.

In practical application of the CCPM, the buffer size is usually determined in several distinct ways depending on the acquaintance level of statistical distribution and on organizational maturity level [8]. Therefore, buffer size can be determined as one half of the total duration of preceding activities. An advantage of using this method is its simplicity and in ensuring a relatively large buffer, while its disadvantage is for not using the positive variation. Another way of defining buffer size is by using statistics, as square root of the sum of squares. The main advantage this approach is the usage of known task variation. However, it could lead to underestimated buffer size for long chains; and as a combination of the two which uses fixed buffer size to account for known variation.

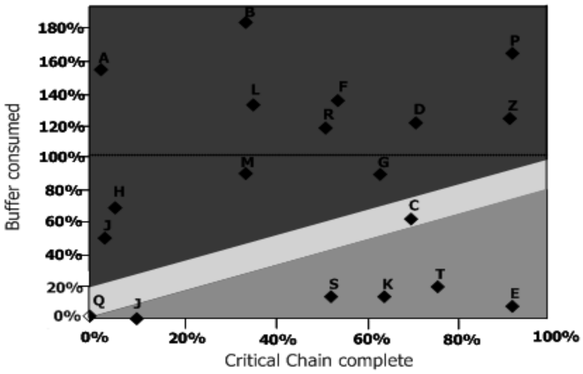

Figure 8. Multi-project fever chart

Additionally, it is advised that critical chain should comprise at least ten activities for effective usage of statistical distribution, that no activity dominates critical chain (e.g. more than 20% of the chain) to minimize influence of the uncertainty of only one activity and that buffer size should not be underestimated (e.g. less than 25% of the critical chain).

4.4 Practical application on network activity diagram

CCPM application does not differ from the CPM/PERT application in the creation of activity network diagram and identification of critical path [17]. From that starting point, process built on Goldratt common steps would suggest [8], [14], [17]:

1. Identify critical chain:
   - Convert early schedule network diagram to late schedule;
   - Replace activity estimates with 50% probable estimates;
   - Add resources and resolve all resource conflicts starting from the latest activity or from the activity with the most conflicts for every single resource.
2. Exploit critical chain:
   - Check critical chain for possible shortenings;
   - Add project buffer at the end of critical chain;
3. Subordinate all other activities, paths and resources to critical chain:
   - Protect critical chain by adding feeding buffers to all feeding chains;
   - Remove all overlapping resources which can occur while adding feeding buffers;
4. Elevate (shorten) initial project schedule.
5. Start over from the first step.

It can be noticed that apart from CPM and usual behaviour during project scheduling, CCPM uses late schedule instead of early schedule. An explanation is found first of all in the fact that late schedule minimizes influence of changes in already finished tasks, that it reduces initial activity cost and that it focuses attention to fewer activities at the project start, especially in a critical chain, which all can contribute to speeding up a project at the beginning [7], [12].

Critical Chain does only contain start dates for every chain and buffer finish date. Due to uncertainty included, it is impossible to determine start and finish date for each activity, i.e. such defined dates would have zero probability [7], [8], [14].

Activity duration uses 50% probable estimate and every estimate with less uncertainty is shortened to 50% estimation [7], [8]. Such larger uncertainty is buffered by creating project buffers using the before mentioned techniques.

It is also noticed that a growing number of software tools have emerged, both standalone and integrated, but their usage does not guarantee optimal results [11], [12], [14]. Practical application of Critical Chain method is successful if a result good enough can be found which will show improvements to initial project schedule [8].

4.5 Multi-project critical chain

CCPM can be applied in a Multi-project environment as well, i.e. to project portfolio in some organization. The constraint in such environment is usually some resource which is allocated to several projects and cannot finish the assigned tasks timely. More details can be found in [8].

4.6 Comparison of CPM and CCPM

It has been already stated that in practical application the basis for applying CCPM is an initial network diagram and the identified Critical Chain.

From that point, CCPM differs from CPM by including resource constrained critical chain, and not critical path as project constraint; it does not change during project execution; it builds from logical dependencies between activities with included resources; sets up activity duration decrease as a goal; uses 50% probable activity duration estimates; does not use multitasking; eliminates date-driven behaviour with exception of project start and finish dates; collects uncertainty in a buffer at the end of a critical chain and uses buffer for project management and reporting [3], [4], [7].

It is important to stress that all changes will not be successful if not accompanied by organizational changes, especially changes in behaviour and thinking, through understanding of current and future behaviour and benefits that would follow [5], [11], [14].

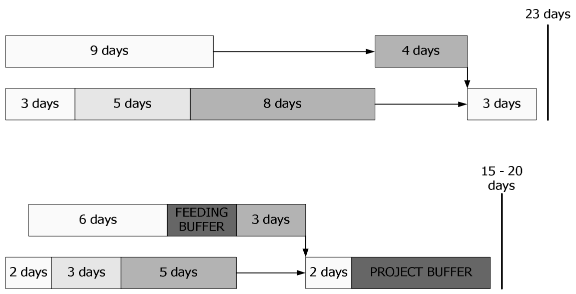

Figure 9. Comparison of critical path and critical chain

5 Conclusion

Since its appearance in the literature, CCPM has fired up a lot of discussion. Many authors almost glorified new approach, while others had critical reviews to the application in Project Management [2], [3], [12], [16]. CCPM critics mainly emphasize that the method has not brought anything new, but merely has combined well known facts, especially from the fields of Operational Research. All of them agree at one point, that Goldratt has uniquely combined those known facts in a single method, which by some authors is a key to innovation [5], [14], [16].

One of the basic shortcomings of the method, especially from the academic point of view, is its simplification and ignoring of specific assumptions. Therefore, some facts have to be included in the analysis [3], [12], [16]:

- Uncertainty covered by initial estimation (50% probable estimation) is heavily influenced by individual estimation and still require empirical support;
- Generic case described by CCPM does not consider more complex network diagrams (e.g. feeding chain could have predecessor activities) and it is not always clear how much buffer should be added;
- Using buffer size estimation as a half of the duration of preceding activities can result in overestimated buffer size, as already stated;
- One has to be aware of all limitations of the buffer usage if used for project management and as a decision basis;
- It is very hard to avoid multitasking in real world; especially if a manager wants maximal resource utilization, resources have to be always allotted to some activity;
- Using resource constraint in portfolio analysis has only one huge shortcoming, it uses for analysis a single moment in time, while in real life, different resources could be constraints at different moments of time;
- For larger project, it is needed to use software tools which contribute to growing implementation costs.

Additionally, different project scheduling methods applied to the same activity set (i.e. network diagram) can result in different results, i.e. different project duration or different critical chain, no matter if critical path or critical chain is used [2], [3].

Some of the authors seek possible cause for emergence of different new methods in a misuse of CPM what resulted in general opinion that the technique is inappropriate [16]. Building from that opinion, CCPM is based on the assumption that estimated activity duration and uncertainty built in such estimate are the main reason for project delays without questioning large amount of external factors to project success [12]. Possible future research could be directed to development of robust project scheduling techniques [2], [3].

Even there is evidence of successful application of CCPM, there is lack of empirical evidence of the reasons for such success. It is possible that success directly depends on organizational project management maturity level, meaning that less mature organizations are more successful in applying CCPM than more mature organizations. Consequently, any methodology applied to less mature organizations could yield significant improvements, which all contributes to less visible reason for successful CCPM implementation [12].

Nevertheless, CCPM with explicit buffer set up as a safety margin from uncertainty, with considering resource availability and setting resource usage alerts, focusing on main activities and resources and continuously observing buffer usage, represents a new way of thinking and possible optimal solution could be to include CCPM in existing project management methodology within organization [12], [16].

Critical Chain Project Management represents a unique and applicable way for setting achievable project completion dates and for project monitoring and control and it provides a focus shift from simple scheduling to resource constrained scheduling [3].

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