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Evaluating CCPM Method Versus CPM in Multiple Petrochemical Projects

Mohammad Taghipour[1*], Fatemeh Seraj[2], Mostafa Amin[3], Maryam Changiz Delivand[4]

[1] Young Researchers and Elites club, Science and Research Branch, Islamic Azad University, Tehran, Iran
[2] Department of Industrial Engineering, Ghiaseddin Jamshid Kashani, Non-Profit University, Qazvin, Iran
[3] Department of Economics, Islamic Azad University, Arak, Iran
[4] Department of Industrial Engineering, Islamic Azad University, Tehran, Iran

Email Address
Mohamad.taghipour@srbiau.ac.ir (Mohammad Taghipour)
*Correspondence: Mohamad.taghipour@srbiau.ac.ir

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Abstract:
Although project management has long been under consideration and various methods have been proposed for timing projects, but they have not been completely responsive to the needs of the project for increasing productivity and customer satisfaction. As a result, increased risks and the incompatibility of the project with the initial Base line plan, necessitate using modern techniques (such as CCPM) as opposed to common methods (such as CPM). And, the cautiousness, and often resistance, of project control users made the researcher implement two of the selected techniques in the breakdown of a petrochemical project – which is a national plan – in the design, supply, and production (EPC) phases, using the results of fundamental research, to evaluate – based on known indicators – and gain better knowledge of the tools. For ranking the indicators, Analytical Hierarchy Process (AHP) was used, and to analyze the methods and implement them, software facilities for project control, such as Primavera6 and CCPM+ were used. Results indicate that there is a philosophical difference between the two approaches, and the reason is using CC in the limitations theory and buffers that cause concentrating on system efficiency and performance and making rules and algorithms, not discussed by the crisis path. Finally, although the use of CC is complex and requires cultural changes, many ideas can be easily utilized by experienced project managers and become an appropriate competitor for CPM in reducing project time and expense.

Keywords:
CCPM, CPM, Project Management and Control

1. Introduction

In the world today, where competition between organizations is a fact, proper management is one of the main elements that while ensuring success, provides customer satisfaction. In executing big projects, many teams and factors are involved

that require correct and quick management to prevent chaos. Project management is utilizing knowledge, skills, and tools required for managing the execution of activities to resolve the needs and expectations of project beneficiaries. Such that when exiting the program it is possible to return the project to the closest state in its initial and main path, by identifying the reasons and mentioning the most economic activities. In fact, a successful project is in accord with the technical and quality specifications and the time and budget framework, so it can provide customer satisfaction; hence, the two elements of timing and control are the main parts of project control and management. The science of project management starts with timing. Since lengthening the duration of a project results in an increase in the finished price (compared to the estimated price), decreased profits, contract problems, and …, these problems can be avoided by proper timing.

Project management concepts were introduced in the late 1950s, and were dominant for more than 40 years. Examination of the projects of the early 1950s indicate a lack of accord and increase in the estimated time and expense with the actual project. In 1957, critical path method (CPM), a solution for overcoming this problem, was defined. This method determines the shortest time to complete the project via the order of activities that have zero total levitation, such that if the time for execution of activities in the critical path change, the project completion time also changes. This method still has a big function in many companies and industries. On the other hand, in some industrialized countries and in defense industry organizations, the critical chain project management method, proposed by Dr. Eliyahu Goldratt in 1997 based on Theory Of Constraints (TOC), is used. Critical chain project management, determines the duration of the project, using relations between activities, the needed resources, and the method of accessing the resources, and for compensating critical activities delay, uses the project buffers at the end of the critical chain. This method is the counterpart to more traditional methods – such as CPM – that emphasize the order of performing tasks and inflexible timing. Whereas critical chain project management method is inclined toward leveling the resources, which requires the resources to be flexible in the beginning and the speed of changing tasks and task chains be high so the project can fit the timing. Examination of the strong and weak points of these methods and their usage in petrochemical projects, as multiple projects, in philosophical and executive levels, and analysis of the reasons for not using the method mentioned in Iran's petrochemical projects, in spite of mot completing many projects in the estimated time and budget, are the subjects under analysis in this study, because unlike industrialized countries this method still does not possess a good position.

2. Critical Path Method (CPM)

Planning means decision-making for the future. There are many methods so that planners can consider all elements and variables related to decision-making: such as Gantt charts, CPM, and the technique for evaluating and reviewing the program. The simplest methods are Gantt charts, introduced by Henry Gantt, and bar charts, introduced by Frederick Taylor. These charts are still used exclusively in many organizations and institutions for showing the beginning and end of activities. These charts consists of two perpendicular axes. The horizontal axis denotes time, and the vertical axis shows the necessary activities in the project. The difficulty with these charts is that they do not show the order of these activities.

The difficulties with these charts and their inefficiency in big projects, made managers think of using other techniques such as Critical Path Method (CPM), and evaluation and review techniques. In the 1950s, a group of scientists in operations research thought of a method for planning projects.

They devised a technique, the longest, non-reducible path of events, for performing basic repairs project in an electric power-plant. This technique was later called the main order technique. It has many similarities to CPM and Program for Evaluation and Review Technique (PERT), but was never officially published.

Almost at the same time of this event (1957) DuPont Production Company, assigned a research group to analyze new management methods in engineering affairs of the company. This group was later completed with Dr. John Muchley, from the scientific research center of Poniuac co., and Mr. Kelly from Remington co. This group was successful in creating CPM.

This method was first used in the project of constructing a factory for Dupont Company. After that, Dupont Company used CPM for fundamental repairs in one of its factories that had a continuous production system. Production should stop for the repairs. So, any measures and innovations that shortened repair time, would be an important help to the company. Using CPM the total time for repairs was reduced from 125 hours to 93 hours, and in later periods to 74 hours.

Among the many methods for analysis, planning, timing and controlling projects, the bar chart technique and network analysis methods are the most common. Network analysis methods that use network diagrams compensate for the shortcomings of bar chart technique. These methods are generally based on Graff's theory. CPM is also a network analysis method [1]. A network is an image of the project that shows the activities in the project and their relations. A network is like a heart in the body of network analysis methods. The project manager, specialists, contractors, and other units can visually examine their conceptions and assumptions regarding project activities and the relation between them, and make corrections, by having access to the network. For drawing the network, which is a visual image of the relations of the project activities, the relations between project activities should be defined and determined [2]. There is at least one path in every network that takes the longest time. This is called the critical path. Critical events in a network are events that have the least levitation (which is usually zero), i.e. between the earliest and the latest date of occurrence of these events is zero. The critical path is a path that passes through critical events from start to finish [3].

The critical path is the most time-consuming succession of events and activities required to complete the project [4]. The length of the project is equal to the critical path.

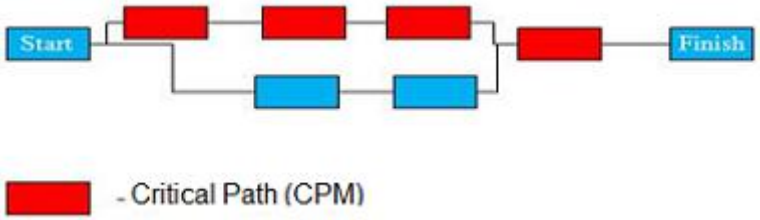

Figure 1. *Sample critical path.*

In the critical path method, with complete consideration of the time of connections, dependencies, and successions of activities, the earliest and the latest start and end

time for each activity is determined and specified. The main consideration of this method is calculating the levitation times and the flexibility in the time of activities [5]. Figure 1 shows a sample critical path.

3. Critical Chain Project Management (CCPM)

In 1997, Dr. Eliyahu Goldratt introduced the first new approach for project management after 40 years with the publication of his best work "critical chain". The ingenuity of Goldratt's method was creating a new shift, which for the first time, collected both aspects (human and methodological) of a project management algorithm is a single framework. Critical chain methodology is based on deep awareness of human nature and his reaction in project management framework. Based on this method, critical chain management performs the project in a much shorter time than critical path method. Furthermore, critical chain method is simpler and the project team is faced with less workload in the planning and pursuing stages.

Critical chain management correctly defines and clarifies the relationship between duration of activities, dependencies, required resources, and method of access to these resources dring the project [6].

There are various innovative methods for solving the timing problem and the limited project resources, and it is possible that the results of these timings are different and different critical chains are presented. It is even possible that different optimal timings cause different critical chains. Based on Goldratt's view, the definition of critical chains are crucial, while these chains are not easily identified and selected [7].

Critical chain is the longest path in the project network, it includes dependencies of the activities and the limitations of the resources. [8] Nowadays in some industrialized countries and defense industry organizations, this method is used for planning and timing projects. In this method, limitations and bottlenecks are removed, by identifying limitations and bottlenecks and injecting more resources to the process. The process of generating a timing program in CCPM is a backward process from the planned end date of the project. In CCPM, the workload in the beginning of the project is reduced, due to starting the activities at the latest time possible, and subsequently delays are reduced considerably. The performance of CCPM is similar to timely production systems.[9,10].

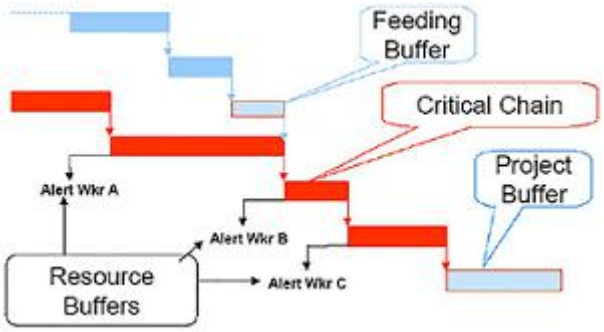

Figure 2. *Mechanism of CCPM.*

CCPM uses buffer management instead of earned value management for efficiency evaluation. Some project managers' view earned value management technique as misleading because it does not differentiate between advancement along the

constraints of the project, along the critical chain, or other paths. Figure 2 shows the mechanism of CCPM very well.

Types of Buffers in CCPM:

Project buffer: Project buffer is, in fact, the difference between the duration of the project based on new estimation, and initial estimation that is shown as a separate activity in Gantt chart but does not cause an increase in the total project duration, and is a reminder of the uncertainty of the project. The size of this buffer is selected to be 50% of the length of critical chain activities.

Feed buffer: For every path that leads to the critical chain, a feed buffer is added. A feed buffer shows the protection level of the critical chain against uncertainty in the feed critical chain, and is located at the intersection of the feed buffer and the critical chain.

(It is noteworthy that the feed buffer and the project buffer are times in essence, like an activity without resources.)

Resource buffer: Resource buffers or Flags have been provided. These buffers are located in the critical path before any activity, so it can ensure the availability of resources. But they do not consume any time, expense, or resources. Their objective is to issue a message to the critical resource, that a critical chain activity that has been assigned to them is starting soon.

4. A review of Research History

In Goldratt's book and the writings of his followers, such as Newbold (1998), Simpson and Lynch (1999), Homer (1998), and Leach (1999), and also in educational books of management and engineering, and professional standards, such as project management science guideline, critical chain has been introduced as a replacement for traditional project planning and control methods.

Globerson (2000) considers it a modern and revolutionary method in project management, because he believes that by shortening the project duration and increasing power, performing obligations of time, expense, and efficiency are increased. Austin (2002) also considers CCPM an unexpected and important advancement for project management since the conception of CPM, and leader of project management in the 21st century.

Taghipour et al.[11], studied Risk analysis in the management of urban construction projects from the perspective of the employer and the contractor.Imbalance between anticipated and actual progress in the development of urban construction projects suggests that there are many obstacles and risks which not only causes the urban management be unsustainable, but the reconstruction and development of urban space is also seriously threatened. the results indicated that the experts listed the most significant risks as the delays in the payment of contractors' claims and statements due to the lack of handling financial instruments, the governance of relationships rather than rules in the tenders resulting from employer actions, low commitment to the quality of work provided by their subcontractors, failure to complete the detail engineering by foreign contractors on time, weaknesses in contractors' financial resources, and offering lower prices than reasonable by contractors to win the tender. Finally, the solutions for eliminating or reducing risks in high risk areas have been offered to provide tranquility for contractors and employers.

Rezvani Befrouei MA et al.[12], discussed Identification and Management of Risks in Construction Projects. Today, risk management in construction projects is considered to be a very important managerial process for achievement of project's objectives in terms of time, costs, quality, safety, and environmental sustainability. Instead of employing a systematic approach for identification of risks, their probability and their effects, most of the studies conducted inthis area have focused only on a few aspects of risk management in construction project. the present study aims to identify and analyze the risks associated with development of construction in the greater city of Tehran, employing a comprehensive approach that is consisted of five aspects. After the collection and observation of the data, the output was examined by Pearson correlation also, using charts and tables. The results indicated that "tight project schedule" present in all five categories- imposed the maximum risk. Also "design variations", "excessive approval procedures in administrative government departments" and "unsuitable construction program planning" were identified as next high risk factors.

The studies of McCallom and Sherman (1991) on research and development projects of 64 advanced technology businesses, by examining the efficiency of matrix organizations found out that the number of performed projects is in direct relation with the organization efficiency indicators. By analyzing two important indicators (capital return, and sales growth), they found out that using one individual in two projects simultaneously is optimal, and using him in three projects does not cause a problem. The reserve alarm is one of the unique attributes of CCPM. This reserve is shown as a virtual activity, so it can alarm the resources responsible for critical chain activities that the prerequisites for the next task have been met and the current task should be completed quickly and prepare for the critical activity.

Others view it as an exaggeration and maintain that it has been years that experienced managers have been working with this method, and the uniqueness of this method is in its name, not nature.

Taghipour et al.[13], studied Analysing the Effects of Phisical Conditions of the Workplace on Employees Productivity. One of the issues that today will improve the productivity of any organization is attention to the human factors engineering. The aim of this study was to find the amount of employee's satisfaction from environmental and organizational factors of their jobs, thus providing guidelines for improving the identified problems which eventually will lead to increase the productivity.

Baghipour sarami et al.[14], studied Modeling of Nurses' shift Work schedules According to Ergonomics: A case study in Imam sajjad (As) Hospital of Ramsar. In this study, 35nurses working in the emergency ward of Imam Sajjad (AS) Hospital of Ramsar city, Iran, were considered. The final model was implemented with GAMS and at the end, shift working with ergonomic criteria were proposed. The results showed that the proposed working program on one hand will improve satisfaction and efficiency of nurses and on the other hand it can decrease the effects of disorders on shift work.

The studies of Hill, Thomas, and Allen (2000) regarding the estimation of the duration of a project's activities and software design in an international financial business gave opposite results. They analyzed the estimated and actual time of over 500 project activities, and found out that only in 8% of the tasks these two times were the same, and in nearly 60% of the tasks, the actual time was less than the estimated

time. These results show that the assumption that this method is an exaggeration is not valid. In 32% of the tasks, the actual time was more than the estimated time, which shows that the certainty margin for reaching 95% assurance level was not sufficient.

Taghipour et al.[15], studied Supply Chain Performance Evaluation in IN The IT Industry. The appraisal of several performance measure agendas and metrics already accessible proposes that supply chain performance measure can be detected under different categories such as cost and non-cost. In this study, developed supply chain of IT industry based on BSC from existing decision making models. Then, industrial projects performance and performance evaluation measures have been determined using a designed questionnaire.

Morton & MCK(1998), Raz et al (2003), and Myler (2003), also question its originality, and believe that CCPM contains known old concepts, but presented in a new way.

And, we can mention the studied by Raz et al (2003) and Globerson (2000) regarding the basic concepts of CCPM and its difference with the critical path method on a conceptual level.

Taghipour et al.[16], studied the Study of the Application of Risk Management in the operation and Maintenance of Power Plant Projects. one of the methods used in good decision making, pay attention to risk management, which is known as an important part of project management and control. Risk management has evolved over time and its systematic method has provided managers with a definite path so that they reduce potential threats to a minimum and reach project goals by the least possible deviations. In this paper, subsequent to an introduction of fundamental concepts of risk, risk management, an account of risk management, methods and its techniques are presented. In the end, following a discussion on how it is practically used in projects in a real and practical sample, risk management and its application are implemented and essential investigations are undertaken into its effects.

Mahboobi et al.[17], discussed Assessing Ergonomic Risk Factors Using Combined Data Envelopment Analysis and Conventional Methods for an Auto Parts Manufacturer. occupational injuries are currently a major contributor to job loss around the world. They are also costly for business. The absence of rational analysis is felt in this area, so mathematical analysis is needed to obtain the logical results of these injuries in order to find gaps or loss points of industry. OBJECTIVE: This paper assesses the effect of five demographic factors on ergonomic risk and occupational injuries using an integrated mathematical programming approach. The obtained results will help managers to carry out any required corrective actions or establish benchmarks.

Taghipour et al.[18], studied Assessment and Analysis of Risk Associated with the Implementation of Enterprise Resource Planning (ERP) Project Using FMEA Technique. Enterprise resource planning (ERP) is one of the latest management tools that can take advantage of information technology to comprehensively gather resources and information in all parts of the organization by an interlocking, system with fast speed and high quality and help users in all organizations and sectors by giving certain modules for managing different sectors such as projects, human resources, and services. Despite the many benefits this system can have for the organization, its implementation and deployment is very risky and costly.

Taghipour et al.[19], studied Construction projects risk management by risk allocation approach using PMBOK standard. Projects' managers in plenty of construction projects which are assumed that are under control, are facing risk as an unknown occurrences and they are attempting to control it and are suffering more costs. Though, by a comprehensible effort and applying risk management, risks are identified and controlled before happening or a plan is provided in order to deal with these occurrences and time and cost are saved. Thus, they have to be controlled and appropriately responded by risk management methods. In this regard, risk management process in PMBOK standard can be a suitable approach to solve this problem.

Taghipour et al.[20], studied The Evaluation of the Relationship between Occupational Accidents and Usage of Personal Protective Equipment in an Auto Making Unit. One of the problems that encounter each work society is occupational accidents. Today, despite the improvements of facilities and working conditions, the possibility of accident occurrence in workplaces and especially in industrial places is inevitable. Since the non-use or misuse of PPE is one of the main causes of accidents in industrial units, the aim of this study is to evaluate the association between occupational accidents and the use of PPE in the body section of a vehicle manufacturing unit. The results showed that there is a meaningful positive relationship between the factor of inadequate PPE and probable hazards of the industrial workplace.

Lipovotsky, Doyer, and Shenhar (1997), analyzing 110 projects, studie the relative importance of different facets of the success of a project. Their findings show that in the view of the customer, the importance of profit is much more than (almost double) the aims of the plan. However, in the customer's view, effective guidance and management of the project by a competent project manager, increases the chance of success of the project. CCPM, like traditional project management methods, emphasizes the success of project management instead of the success of the project; it views the project only from one angle and that is attaining the goals of the program [21]. Other studies have also focused on the technical aspect of CCPM timing [22,23].

Taghipour et al.[24], studied Necessity Analysis and Optimization of Implementing Projects with The Integration Approach of Risk Management and Value Engineering. Risk management and value engineering have appeared as modern management tools since the mid-19th century and have been used separately in different projects. Due to the ineffectiveness resulting from separate implementation of the two approaches in major projects as well as the similarity between them in terms of their goals and executive structures, this research tries to analyze the separate role of each approach in the project process and examine the possibility of integration and correlation between their different phases. This article aims at introducing and examining a tool that simultaneously has the capability of the two categories.

Taghipour et al.[25], studied Evaluating Project Planning and Control System in Multi-project Organizations under Fuzzy Data Approach Considering Resource Constraints. Projects can be repetitive tasks in specified periods of time and also it may involve some functions which are performed just once. However, in any project, managers and experts consider three basic and important goals: least time, lowest cost and best quality, so all efforts are directed toward achieving these basic goals. Statistics indicate that projects are either conducted on estimated time or delayed and rarely are delivered before due date.

Taghipour et al.[26], studied Implementation of Software-Efficient DES Algorithm. By increasing development of digital telecommunication and the increase of sending and receiving data of various network of data transfer, protection of the safety of data are the most important necessities of the current world. The increase of different bank trading, increasing use of smart cards, moving to electronic government, are the examples of significance of this issue. In this study, an efficient algorithm implementation by MATLAB and C language is presented and is compared with the latest works in this field.

In a study regarding the estimation of activity durations in the software developed by Hill et al (2000) opposite results were obtained. In this study, they analyzed the estimated and actual time of over 500 project activities, and found out that only in 8% of the tasks these two times were the same, and in nearly 60% of the tasks, the actual time was less than the estimated time. These results show that the assumption that this method is an exaggeration is not valid. In 32% of the tasks, the actual time was more than the estimated time, which shows that the certainty margin for reaching 95% assurance level was not sufficient [27]

Taghipour et al.[28], studied Risk assessment and analysis of the state DAM construction projects using FMEA technique. Dam construction projects are the most important projects of the country and absorb a considerable amount of the state budget on annual basis. As they take a long time to be completed, they always face risks and many uncertainties. In this study, the researcher intends to use a highly applied qualitative-quantitative methodology (FMEA) to analyze the risks of state dam.

Taghipour et al.[29], studied the impact of ICT on knowledge sharing obstacles in knowledge management process.Today, knowledge is known as a valuable asset in any organization so management of such insensible asset is one of the factors cause success in organizations. But knowledge can be effective when it is shared across the organization. Therefore, knowledge sharing is a key element in the process of knowledge management. This study aimed to check the impact of ICT on knowledge sharing barriers in one of the mobile operator, in Tehran.

Golgoon (1387) in a study, managed the project of constructing some equipment in the 9th-Alfin complex at Assalouyeh, Iran, using CCPM. Results indicate a reduction in project time compared to CPM. In another study he has paid attention to positive analytical-critical items. [30].

Taghipour et al.[31], studied Assessment of the Relationship Between Knowledge Managment Implementation and Managers Skills. The Purpose of this study is to consider the effects of knowledge management implementation on manager’s skills of Reezmouj System Company. Results showed that there is a relation between knowledge management.

Taghipour et al.[32], studied Evaluation of the effective variables of the value engineering in services. The value engineering is a systematic method for resolving the problems, reducing the cost and improving the function and quality simultaneously and this leads to the increase of customer satisfaction by investigating and improving the value index. The results of this research which are based on the post managers and specialists responses show that applying value engineering by the post managers has significant effects on reducing the cost, saving time and customer satisfaction.

Sayyah (1380) has reported the results of using CCPM in the project of constructing a 10-KW wind turbine. These results indicate a reduction in the project time. [33]

In a study, the use of CCPM in the project of making ticket reservations at Northwest Airlines was analyzed. In this report, the assignment of a competent and educated project manager was considered an important step in the implementation of CCPM. [34]

5. Research Method

For evaluating and comparing the two techniques mentioned, first the most important evaluation indicators on philosophical and operational levels including two phases of planning and control were identified and were rated using a questionnaire and AHP. Considering that this study is not based on statistical analyses, there is no need to determine a statistical population and sample. Interviews with project management and control experts were carried out in a consulting engineering company. Then in order to analyze the methods and implement them, the software capabilities regarding project control, such as Primavera6 and CCPM+ specialized software, were used. In the software section, in order to accurately evaluate and compare the methodologies and techniques, they were implemented in the structure of one of the national petrochemical projects, and the results were analyzed, benefits and shortcomings of the two methods based on the most important indicators, and the reasons for using or not using the mentioned methods are also analyzed.

Determining indicators and prioritizing them using EXPERT CHOICE software:

After determining the indicators based on prior studies [35], for ranking them, the AHP method – which is Multiple Attribute Decision Making (MADM), is used. MADM refers to making specific decisions, such as evaluating, ranking, or selecting among available choices, performed in a wide decision-making space.

AHP was proposed in the 1970s by Saati. It is one of the most important multiple attribute decision-making techniques. It divides a problem into many levels, and the sum of these levels, create a hierarchy [36].

Therefore, this approach has the ability to solve complex problems in various fields. In this regard, in this method, after applying 9-digit values, n x n matrices for each n elements, are formed. For each element, an importance coefficient (W) is obtained. In this way, the superiority of criteria i to criteria j, a_{ij} is determined and all criteria are compared in pairs.

Table 1. *Theoretical indicators, Planning and Control on multiple projects level.*

Theoretical indicators	Planning indicators on multiple projects level	Control indicators on multiple projects level
A- Theory	-	-
B- Objectives	A- Objectives	-
C- Concentration	B- Concentration	A- Concentration
D- Uncertainty	C- Resource management	B- Uncertainty
E- Resource management	D- Uncertainty	C- Resource management
F- Behavioral aspects	E- Behavioral aspects	D- Behavioral aspects
-	F- Timing	E- Tools and control standards

After performing calculations by the software and normalizing the numbers, the weight of the elements is obtained. The weight of each element shows its importance and value, compared to other elements. Figures 3 thru 5 show the results:

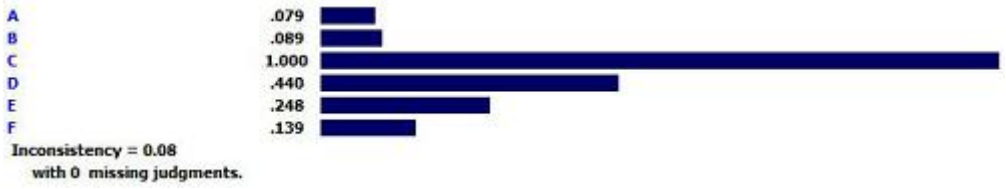

Figure 3. *Ranking the indicators on a theoretical level.*

Figure 4. *Ranking the indicators in the planning phase.*

Figure 5. *Ranking the indicators in the control and monitoring phase.*

As it is shown in the figures, on a theoretical level concentration; in the planning phase the resource management option; and in the control and monitoring phase, the tools and control standards option were identified as the most important evaluation indicators. The inconsistency on the theoretical level was 0.08, in the planning phase 0.04, and in the control phase was 0.02. Considering the fact that in all three groups the inconsistency is less than 0.1, the results are acceptable.

5.1. Planning using CPM and CCM

After determining the limits of the project (Reasons; description of the product and goal; deliverables; objectives; complementary items including assumptions, risks, working limitations, …), identifying the project activities, and breaking the project into smaller parts, and preparing a WBS diagram regularly and systematically using the top-down method, which considering the type and form of organizing and the spread of the project, based on the execution phases of the project, the project;s main tasks, the final product and its components, participant units in the project, or a combination of these, determining the project executive events (milestones) for easing later controls, and emphasis on ending some crucial activities n a specific time, determining the order of activities, and drawing the network based on the logical relation between activities and planning the project via the CPM method using PRIMAVERA software and via the CCM method using the CCPM+ software.

In the CPM method, considering that the project completion time was agreed upon with the employer, the start date of the project was specified using software. The start date considered was Feb. 19th, 2013, and the end date is Mar. 19th 2017. Figure 6 shows the Gantt diagram via the CPM method.

In CCPM, planning using the As Late As Possible (ALAP) method was selected. Doing so, the software calculates the project start date and the latest start date that satisfies the final objective. By this, ccontrary to CPM, the critical chain, using the temporary reserve, project end date is protected against the duration increase. In this method, the duration of the activities is specified and halved and converted estimates

of 85% to 95% of the critical path to 50%. Every activity was planned at the latest time possible. In fact, estimated times in CPM are considered safety time. In this case critical activities increase. Then the assigned resources and the phenomenon was performed. Finally, after the levelling the resources in the project buffer, the feed buffers, and source buffers were added.

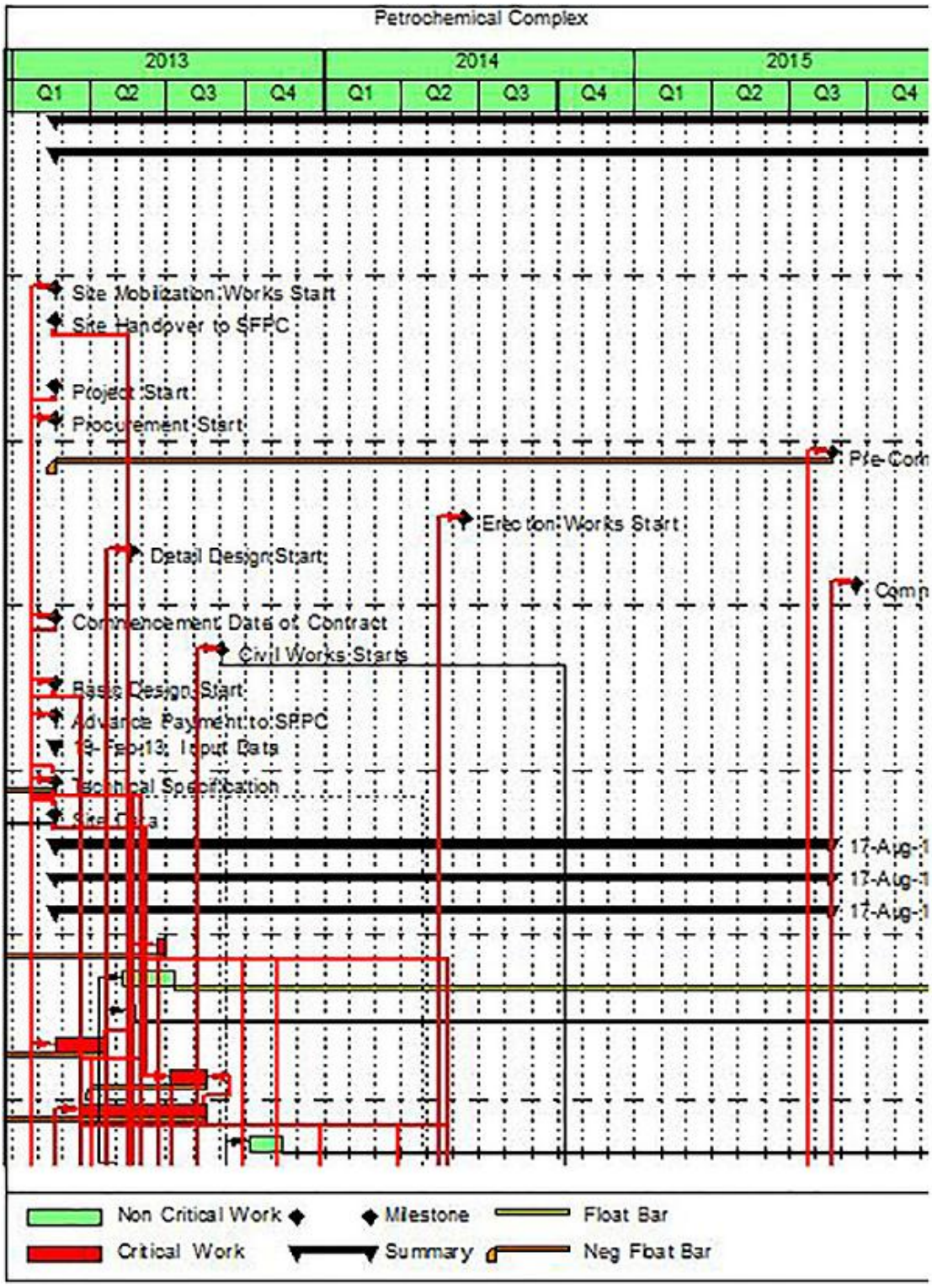

Figure 6. *Gantt project timing using CPM.*

The start date of the project based on CCPM is March 4th, 2012 and the end date is Jan. 4th, 2017.

5.2. Data analysis

The discussion in this section is structured in three parts. In part one the two implementation methods are compared in the CCPM+ and p6 software based on time and expense. In the second part, buffer management is analyzed in the critical chain method. In the third part based on the indicators ranked on a theoretical level and operational level, in multiple projects are compared. The executive level includes planning and control phases. In the fourth part, the strong and weak points of the two method are examined.

Table 2. *Comparing the two methods based on time and expense.*

Method	Start date	End date	Working days	Total expense	Project buffer
CPM	Jan. 19th, 2013	Mar. 19th, 2017	1490	4812600000000	0
CCPM	Mar. 4th, 2013	Jan. 4th 2017	1430	4186962000000	60 days

Considering that the project start date in CPM, based on mentioned dates, as is specified, the project in the critical chain method started 15 days later, and the size of the project buffer is 60 days, therefore the project started later than in CPM method. Furthermore, the number of working days shows a 4.02% decrease, which has caused a 13% expense decrease.

5.3. Buffer Management and Analyzing the Situation

Buffer management is a tool for pursuing and controlling the project execution in the critical chain method. Since uncertain estimation is used, precise methods, such as variance analysis, and added value are not used. Instead, based on the buffers used, decisions are made.

If we divide the buffers into three parts, if the size of the buffer is in the green area, project management is not required to do anything, and the project continues as planned. If the size of the buffer is in the yellow area, management should identify the obstacles and offer possible solutions. If the size of the buffer enters the red area, then the management should move out of the red area by speeding up tasks and exchanging expenses for time, otherwise it is possible to face delays in the project.

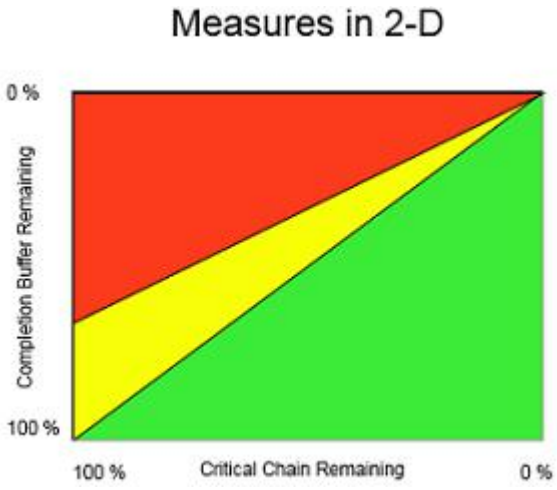

Figure 7. *Display of three buffer areas and their meanings.*

Since in the critical chain method, project control and management which includes preparing a table of buffer conditions, registering buffer condition in time periods with appropriate total project time, monitoring the condition of buffers, making decisions, and informing available sources of outputs, using the following buffer management diagram can help with the ideal advancement of the project.

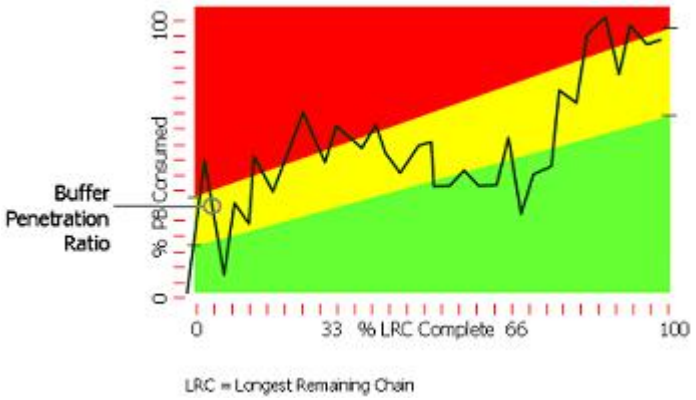

Figure 8. *Buffer management diagram.*

Considering that a buffer is located in the yellow area, the existing obstacles were identified and resolved. Based on the above diagram, with 40% advancement of the project, about 45% of buffers in the green area were used, which indicates the ideal advancement of the current planning.

5.4. Comparison of the two methods based on ranked indicators

5.4.1. Theoretical level

This level is usually not explicitly addressed in articles, while it is very important for understanding the methodology on the operational level.

a. Critical chain:

• Theory: System theory, Graff theory, and Theory of Constraints

• Objectives: Minimizing individual project time while considering limitations of resources, increasing project output in the environment of multiple projects and fulfilling the objectives of time, expense, and limitations with special emphasis on meeting the assigned project deadline.

• Concentration: System view both in the individual project environment and in multiple projects, specifying the completion date of the project and which activities need special attention, while considering the uncertainty explicitly so as to prevent delays in completing the project,

• Uncertainty: Possible planning based on Monte Carlo simulation and risk analysis in order to protect against external possible events, general protection against uncertainty, and exchanges between the three main objectives of the project.

• Resource management: Solving RCSP in order to develop baseline timing, with the difference that it considers the buffers, and maximizing the use of bottleneck resources

• Behavioral aspects: Reducing activity length in order to nullify individuals' inclinations for delaying activities (Parkinson's law)

b. Critical path:

• Theory: System theory, Graff theory

• Objectives: Minimizing individual project time while considering limitations of resources and fulfilling the objectives of time, expense, and limitations

• Concentration: Individual project view, specifying the completion date of the project and which activities need special attention, so as to prevent delays in completing the project,

• Uncertainty: Possible planning based on Monte Carlo simulation and risk analysis in order to protect against external possible events, specific protection against uncertainty, and exchanges between the three main objectives of the project.

• Resource management: Solving RCSP in order to develop baseline timing, with the difference that it considers the buffers, and maximizing the use of bottleneck resources

• Behavioral aspects: Human management aspects are referred to only figuratively.

• Comparing the two methods based on operational indicators (Project planning phase)

c. Critical chain:

• Objectives: Maximizing system output

• Concentration: Efficiency of multiple projects while considering limited resources and reduction in WIP

• Uncertainty: Identifying and using capacity and drum buffers

• Resource management: Maximizing use of limited resources and has not discussed multiple duties

• Timing: Placing system limitations in focus, using capacity and drum buffers, and prioritizing the projects and eliminating contradictory resources in the system

• Behavioral aspects: Preventing multiple duties

d. Critical path:

• Objectives: Minimizing project duration

• Concentration: Individual project efficiency

• Uncertainty: Not discussed

• Resource management: Maximizing the use of all resources and not allowing multiple duties

• Timing: Project prioritizing rules

• Behavioral aspects: Not discussed.

• Comparing the two methods based on operational indicators (Control and monitoring phase)

e. Critical chain:

• Concentration: Supporting bottleneck resources

• Uncertainty: Capacity and drum buffers

• Resource management: Identifying and using capacity and drum buffers

• Timing and reiterating timing: General system management using drum buffers and controlling the entrance of new projects

• Control tools and standards: Number of completed projects (output), WIP

• Behavioral aspects: Responding is not clear. Preventing multitasking

f. Critical path:

Concentration: Preventing changing the critical path

Uncertainty: For individual projects, not multiple ones

• Resource management: Maximizing the use of all available resources

• Timing and reiterating timing: Different prioritizing rules

• Control tools and standards: Added value report has not explicitly been addressed in multiple projects

• Behavioral aspects: Not discussed

5.4.2. Strong and weak points of CPM and CCPM

a. Advantages of CPM:

• Providing a graphical representation of the project. Gantt diagram and resource histogram are better and more logical in CPM

• Predicting the time required to complete the project

• Concentrating in the critical path and activities in order to protect timing and avoid delays

b. Disadvantages of CPM:

• The big disadvantage of CPM is that there usually is uncertainty in the estimated times and the project is often delayed

• Total expense estimate is more than in CCM

c. Advantages of CCM:

• This method contains good ideas but it should be made common in PM and PMBOK should be taken more seriously.

• Expense estimate is less than in CPM

• Buffer management and its constant monitoring, and the ease of pursuing the project

• Constant reviewing without changing the end date

• Considering resource availability, and more concentration on resources in addition to time

• Concentrating on the project and a comprehensive view instead of focusing on activities and having a detail-oriented view

• Providing “speed-up” alarm to critical resources in advancing activities

• Shortest realistic timing plan compared to other available methods considering the resources

• Systematizing project-oriented companies in conditions of weak management

d. Disadvantages of CPM

• High cost and limitations of related software for implementing the method.

• High cultural cost for implementing CCPM, and contradictory views of experts regarding its use

• Considering that if there is not sufficient space for adding feed buffers, there is no solution offered. Therefore if CCPM adds to the project buffers, the timing increases, and that is in contradiction with the objective of CCPM, which is shortening the time

• In CCM, which is obtained from the theory of constraints, the most concentration is on the issue of project timing. In this method, considering that time buffers are implemented in the project and does not have anything to with other expense items, it can be said that it is its biggest limitation

• Activity times and safety margins

• An appropriate formula for very high matching in order to reduce the activities' time estimates and finding a dependable safety margin, since the timing uses the leveling algorithm of resources and generally uses innovative rules.

6. Conclusion

Considering that the main objective in changing the method of planning is eliminating the delays in the project deadline, CCPM accepts the superior assumption that uncertainty in the time of an activity is a basic factor that affects the timely completion of projects. Whereas this fact, that incorrect pressures and policies and the incorrect estimation of activities can be a hurdle in this matter, cannot be ignored, since the potential, ability, sharing, and experience in project management is very important and changing the tools can assist this issue, otherwise different tool will not have much efficiency. Therefore, the first and most important step in using CCPM is cultural changes in the organization and software limitations which improve the morale and the efficiency of team members and their acceptance of change, which seems impossible in a short time. The other point in presenting this innovative algorithm is estimating the time of the activities and buffers. This method is the most matching with reality and is a strong competitor for projects that have an estimated time like CPM. As a result, the project is completed in a shorter period of time with less expense, without changing the constraints of the project. Hence, customer, employer, and contractor satisfaction is provided. The executors have an effective tool for harmonizing the projects based on the priority and organizational capacity. It is noteworthy that the first step in using CCPM in any organization, is considering the expenses and the resulting profits and the time for transfer from the break-even point. It seems that the purchasing expense and development of this method compared to cultural changes is less.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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