CRITICAL CHAIN PROJECT PLANNING IMPROVEMENT IN TERMS OF QUALITY AND DURATION OF PROJECTS

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ABSTRACT
The present paper discusses the results of an experiment I conducted during my PhD studies. The experiment had as main goal the study of Critical Chain planning impact on the results of a project, mainly those regarding resulted product quality and overall project duration. The statistical hypothesis I developed the experiment on was that projects planned using Critical Chain planning help end projects faster and deliver better quality results. As far as research methodology employed, I focused on design of experiments, statistical hypothesis testing, and ANOVA Analysis. The results of the experiment clearly show an improvement in overall project duration and quality of resulted products when Critical Chain planning is used.

KEYWORDS: *project management, critical chain planning, design of experiments, ANOVA Analysis.*

JEL CLASSIFICATION: *O21*

1. INTRODUCTION

The Critical Chain Project Management (Goldratt, 1997) has been a result of the Theory of Constraints (Goldratt, 2004), developed by Dr. Eliyahu M. Goldratt in the 80's. Being a relatively new concept, a lot of companies still struggle with it, trying to understand its benefits and the way it works. Although some foreign companies have already registered significant improvements after implementing Critical Chain Project Management (Goldratt, 1994), no Romanian company has managed to successfully implement it, and most of them aren't even aware of its existence.
In theory, this method permits higher project gains without significant investment. Based on the study of the relationship system of precedence among tasks, and also on the dependency between tasks and resources, Critical Chain Project Management changes the way in which we plan projects, taking into account the fact that the resources are never available in unlimited quantities. Aiming at a moderate loading of all resources involved in the project, this planning method manages (at least in theory) to keep the project on schedule and delivers better quality results. I will not go further into explaining the mechanisms that make it deliver those better results, since I've already done that in a number of previous articles, but I will focus instead on the experiment I designed.
As I previously stated, no Romanian company has managed to successfully implement this planning method. Therefore, I deemed worthy to undertake an experiment that would prove the benefits of using it in our national environment.
The hypothesis I developed the experiment on was that projects planned using Critical Chain end faster and deliver better quality results than those planned using the classical Critical Path (Mantel & Meredith & Shafer & Sutton, 2001). To test the hypothesis, I studied the results of 2 projects taking place at the same time; one planned using Critical Chain Project Management and the other using Critical Path Planning. I will further shortly describe the main statistical instruments used during the experiment.

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2. METHODOLOGY

The main instruments I used in my experiment were the design of experiments technique and ANOVA Analysis. I will shortly explain the way they function in the next paragraphs.

2.1. Design of experiments

Developed as a technique in the 1902's by R.A. Fisher in England, the **design of experiments** aims at testing two or more methods in order to determine the best one; or to determine the level of controllable factors which optimizes the result of a process meant to minimize instability of a response variable.

Example: The Manager of a paint shop would like to know whether different additives affect drying time of the paint, so he can choose the one that dries paint in the shortest time.

When designing experiments, we always start from a statistical hypothesis.

My research compared two planning methods for projects, namely the **Critical Path** and the new **Critical Chain**.

The steps I took in demonstrating the hypothesis were:

- Hypothesis formulation;
- Designing the experiment to prove the hypothesis;
- Choosing resources for the experiment that are homogenous as far as experience and knowledge on project planning go;
- Experiment Development;
- Data collection;
- Data interpretation.

The experiment itself was simulating in laboratory conditions the planning and execution of a small house construction project. It would be done simultaneously by two teams, one that would use the Critical Chain planning technique and another one that would stick to the traditional approach of Critical Path planning.

2.2. ANOVA Analysis

Analysis of variance (ANOVA) can help determine if two or more samples have the same "mean" or average. This is a form of hypothesis testing, in which we take into consideration two hypotheses (Andrei, 2003).

The null hypothesis is that the means are equal, which means the samples are statistically similar:

$$H_0: Mean_1 = Mean_2 \qquad (1)$$

The alternate hypothesis is that the means are not equal, and the samples are statistically different:

$$H_a: Mean_1 <> Mean_2. \qquad (2)$$

An easy way to create an ANOVA is to use MS Excel's Analysis Tool Pak Add-in.

3. THE EXPERIMENT

First of all, I picked a significant sample of 12 U.T.C.B. (Technical University of Civil Engineering Bucharest) students, with similar training and planning capabilities. I divided the sample into two teams of 6 people, and I appointed an experienced project manager for each team; both of them were working for TUNGAL S.A. and had roughly the same background in planning and execution of construction projects. The teams I assembled were, as such, very similar to each other and very similar to a real construction project team that operates in the Romania environment.

One team (Team B) has been initiated, over a 2 month period, in planning projects using the Critical Chain. They had to undergo a training that took place in the December 2008-January 2009 time frame, and was held an TUNGAL S.A. headquarters. The specific elements covered by the training included:

- An overview of the classic project management concepts, although the team was fairly familiar with them from their practice;
- An introduction to the Theory of Constraints philosophy, with clear examples from the surrounding environment;
- Project monitoring in terms of time and costs by using the so-called baselines (snapshots of projects at different moments in time, based on which we can see how much the projects slide from the plan);
- Calculating task durations based on probabilities in Excel (usually the Monte Carlo simulation is used for this, but for the Romanian construction environment Excel is better, since it is an instrument most constructors are familiarized with);
- Duration reduction by setting a single buffer, at the end of the project, instead of individual time reserves for tasks; the buffer is calculated so as to ensure a 50% chance to finish the project tasks on time, instead of the usual 90% chance;
- Costs reduction by better resource allocation within the project;
- The management of project portfolios, which usually generate specific problems that Critical Chain addresses;
- Essential elements of Critical Chain planning using MS Project;

Once the training was completed, the two teams simulated, in laboratory conditions, the planning and execution of a house construction project, using a given set of resources. The simulated project was split into 10 tasks (Pinto, 2006), as seen in Table 1.

Table 1. Project Tasks

	Task
1	Pre-feasibility Study
2	Feasibility Study
3	Business Plan
4	Technical Project
5	Execution Details
6	General Chart of Investment
7	Foundation
8	Ground Floor
9	Attic
10	Exterior

Source: own creation

Teams were presented with the same base data, which they had to work on to create a plan for the timely execution of the first 6 tasks, which consisted mostly of writing some specific documents for the construction project.

As far as the actual construction stages, the teams had the same set of resources, which are presented in Table 2, that they had to work with. I have to mention that I created a simplified version of a house construction project, neither the actual tasks nor the resources involved being all that’s needed to build an actual house.

Table 2. Resources available

	Resources	Available quantity	Individual Norm	Cost/unit
1	Bricklayer	4	8 hours/day	1200 EUR/mon
2	Carpenter	3	8 hours/day	600 EUR/mon
3	Electrician	1	6 hours/day	500 EUR/mon
4	Unqualified Worker	10	8 hours/day	300 EUR/mon
5	Plumber	2	8 hours/day	1000 EUR/mon
6	Architect	2	4 hours/day	1200 EUR/mon
7	Furniture			10.000 EUR
8	Staircase			1000 EUR
9	Door			150 EUR
10	Parquet			3 EUR
11	Paint			2 EUR
12	Cement			2 EUR
13	Tile			25 EUR
14	Window			190 EUR
15	Electrical Installation			1200 EUR
16	Building Materials			1000 EUR

Source: own creation

The actual construction phases were conducted using **two sets of miniature house models**, that the teams were allowed to use as soon as they finished the documentation and proved that their project plans would benefit from enough resources to end each task in due time.
The resource pool was sized so that some resources couldn't handle being involved in two simultaneous projects. For instance, if both teams would plan the **Attic** task at the same time, a bricklayer over allocation would occur, which would result in a delay of that task. Resources *would primarily be allocated to the activity that was planned to start sooner* if such a situation would arise. Thus, if one team would plan and be able to start the **Attic** task (all previous tasks completed) even a couple hours sooner than the other, it would get the resources needed to complete it, while the other team would have to wait.
Thus, over the course of the project there were over allocations of the following resources: *carpenter*, *electrician*, *architect*, and in one case even a shortage of *bricklayers*.
At the end of each task the jury evaluated the results of each team, comparing them to the plan the teams created at the beginning. The evaluation had two main directions, namely:

- **The quality of the deliverable** resulted from the task;
- **The compliance with the planned duration** for each task.

4. RESULTS AND INTERPRETATION

After an evaluation from an official jury teams got grades on all tasks regarding quality of results, which are presented in Table 3, and regarding timing, which are presented in Table 4. In both cases, Team A was the one that planned according to the Critical Path principles, while Team B planned according to Critical Chain rules.
For the ANOVA Analysis I used Microsoft Excel, which provides users an add-in for performing various statistical analysis, including ANOVA. Thus, after transferring the data resulted from the project in Excel format, I used the *Data/Data Analysis/Anova: Single Factor* menu to launch the analysis.

The first analysis I did was the one regarding **resulted quality** of the deliverables from the two projects. The input data I used is presented in Table 3.
In the *Input Range* box I entered the grades given by the jury to the deliverables resulted from the project tasks, grades given on a scale of 0-1 (1 being the highest).
I selected *Grouped by Columns*, because I organized my data into columns, as we can see in Figure 1.

Table 3. Project Quality

	Team A	Team B
Task 1	0.60	1.00
Task 2	0.70	0.80
Task 3	1.00	0.90
Task 4	0.80	0.80
Task 5	0.60	0.70
Task 6	0.60	0.90
Task 7	0.90	1.00
Task 8	0.50	0.80
Task 9	1.00	1.00
Task 10	0.70	1.00

Source: own creation

I chose an α risk factor of 0.5, which provides a 95% degree of confidence in the analysis' result. The ANOVA result is the one presented in Figure 2. What does it tell us?

- SS represents the square sum of the average deviations, or **dispersion**.
- Df represents **the number of freedom degrees**.
- MS is **mean square**, some estimate of the variance based on certain sources of variation available to us in our experiment.
- F is a statistical indicator computed as **MS Between Groups** divided by **MS Within Groups**. If calculated F is higher than F_{crit} we reject the H_0 hypothesis, according to which the two data populations have similar averages, and we conclude they are significantly different.

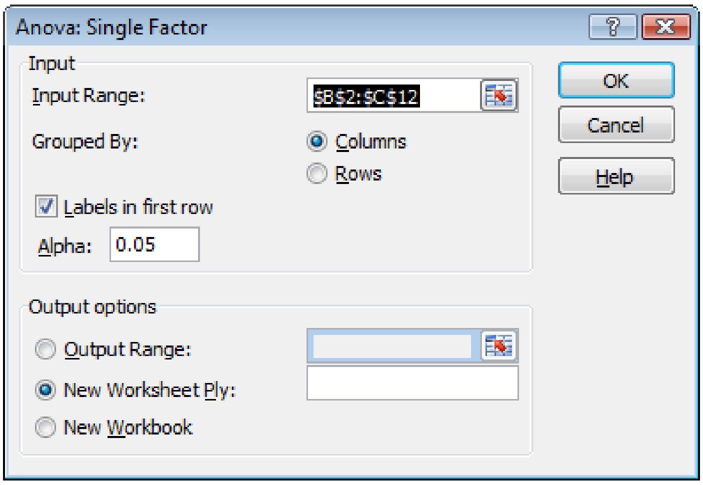

Figure 1. Single Factor ANOVA in Excel
Source: MS Excel

	A	B	C	D	E	F	G
1	Anova: Single Factor						
2							
3	SUMMARY						
4	*Groups*	*Count*	*Sum*	*Average*	*Variance*		
5	Team A	10	7.4	0.74	0.031556		
6	Team B	10	8.9	0.89	0.012111		
7							
8							
9	ANOVA						
10	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
11	Between Groups	0.1125	1	0.1125	5.152672	0.035732	4.413873
12	Within Groups	0.393	18	0.021833			
13							
14	Total	0.5055	19				

Figure 2. ANOVA Results on Project Quality
Source: MS Excel

A SUMMARY section analysis tells us that the average quality of the Team A's project is lower than the average quality of Team B's project (Isaic - Maniu, 2001). In the ANOVA section of Figure 2, MS Between Groups is almost double as much as MS Within Groups, which leads to a calculated F of 5.152672. When compared to the F_{crit}, we realize that $F_{calculated} > F_{crit}$, which means that there ***are significant differences between the resulted quality of the two projects, Team B having better results***. Again, Team B was the one that planned using the ***Critical Chain***.
The second analysis I've done was aimed at the **timing of the projects**, their compliance with the planned delivery terms.
The input data is that in Table 5, the identity of the two teams remaining the same as in the first case. The grades given by the jury were computed by dividing the actual duration needed to complete the task by the planned duration. Thus, a 1.20 grade means that the team needed 20% more time than they planned in order to finish the task.

Table 5. Timing

	Team A	**Team B**
Task 1	1.00	1.00
Task 2	1.00	0.70
Task 3	1.50	1.00
Task 4	1.10	0.70
Task 5	0.80	0.60
Task 6	0.80	0.70
Task 7	1.20	1.00
Task 8	0.70	0.80
Task 9	1.20	0.90
Task 10	0.90	0.80

Source: own creation

ANOVA was generated the same way, and the result is that presented by Figure 3.

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Team A	10	7.4	0.74	0.031556
Team B	10	8.9	0.89	0.012111

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.1125	1	0.1125	5.152672	0.035732	4.413873
Within Groups	0.393	18	0.021833			
Total	0.5055	19				

Figure 3. ANOVA Results on Timing
Source: MS Excel

As we can see in the SUMMARY table, this time the average in better for Team A, but this means that they needed, on average, more time to meet the objectives set for each task (Isaic-Maniu, 2001).In the ANOVA section of Figure 3, MS Between Groups is again almost double as much as MS Within Groups, which leads to a calculated F of 5.05618. When compared to the F_{crit}, we realise that $F_{calculated} > F_{crit}$, which means that, again, there ***are significant differences between the timing of the two projects, Team B having better results***.

5. CONCLUSIONS

The conclusion is simple. The team which planned the construction of the small house according to the Critical Chain principles obtained in the end sensible better quality results and better compliance with the delivery terms originally agreed on.
Again, the starting data which the teams used for planning was the same, their skills were very similar, the only thing different being the planning philosophy used. Using a single resource base, I assured their insufficiency over certain time intervals, in order to better simulate the reality of lack of resources that most construction companies face, due to their constant involvement in a multi-project environment.
As the experiment showed, planning on Critical Path in a multi-project environment leads to an over allocation of resources during certain time frames, over allocation that can invalidate planning logic, making non-critical tasks into critical ones and delaying the delivery deadline of the project.

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