

MAKING ENGINEERING PROJECTS MORE THOUGHTFUL WITH THE USE OF FUZZY VALUE- BASED PROJECT PLANNING

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Abstract: Generally, engineering projects are getting bigger and bigger and more complex to handle. Due to the developments of information technology, managers have the opportunity to plan the execution of their projects and calculate the critical paths of those projects precisely, regardless of the types and sizes of their projects. However, these indicators are not realistic; in many cases the predetermined partial-deadlines cannot be kept, therefore the end of the project must be postponed. The aim of the research is to modify the inputs of the critical path method with the application of fuzzy values. The use of fuzzy values in business planning can support project managers in building the uncertainty factor into their model.

Keywords: Fuzzy logic, Critical path method, Project management, fuzzy critical path method

1. Introduction

As a result of globalization - in almost every competitive market - companies have to put a lot of effort into making their production efficient and keeping it updated. There are a lot of existing tools, which play an important role in keeping companies efficient and productive. Mathematical methods (e.g. linear programming, simulation techniques, etc.) in the field of production management are widely applied, and due to Information Technology (IT) developments in recent decades these methods have become easier to use [1]. As the project management has a very good IT-supported background (e.g.

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Microsoft Project), even complex and complicated projects have become manageable. However, enterprises of Small and Medium Sizes (SMEs) do not always have the financial means to buy project management tools. Nevertheless, if a company is familiar with the mathematical background of project management techniques, particularly how to create a project's critical path or calculate slack times, they will find a cost-effective way solution to carry out the same analysis as are done by expensive software. This is what is presented in the following research.

2. Theoretical background

2.1. Project planning, project critical path

According to literature [2], [3] the following attributes determine the type of the process:

- 1) technology and operator's competence;
- 2) product features.

Project manufacturing has technological focus, which means that companies must build their machines in a way that makes it possible for them to respond flexibly to their customers' needs in project production systems [2]. According to product feature approach, the product must be unique or it must be produced in a small variety in project manufacturing systems [2].

Recently, project managers have to face more challenging and more complex tasks. Not only logical thinking and good soft skills, but mathematical tools are also required to handle these projects [4], [5]. Companies should monitor and control their projects in order to be able to accomplish sub-tasks on time and within planned costs [4]. What is more, scheduling is one of the most important segments in project planning, because it provides a rough estimation for total process time and total process cost [4].

Critical Path Method (CPM) was invented as a result of demands for chemical plants at DuPont in the late 1950s [4]. The essence of this technique is to determine critical and non-critical tasks in a project. Those tasks, which are on the critical path has a crucial effect on the project's lead time, because this path is the longest of all the paths in the project [5].

Operations research can contribute to the success of identifying the critical path in a given project with the help of a mathematical solution [6]. This type of technique is called network method and the equations can be seen below [6], [7]:

Objective:

$$\min z = x_n - x_1, \quad (1)$$

Constraints:

$$x_j \geq x_i + t_{ij}, \quad (2)$$

where x_n is the closing event of the project (the latest event time is when the event must be finished without delay in the network (LT)); x_1 is the early event time of the project (the earliest event time is when the event can begin (ET)); x_j is the next activity within the project; x_i is the previous activity within the project; t_{ij} is the process time of activity x_i .

2.2. Fuzzy logic and fuzzy values

Modeling real life is always a complex and complicated task. In several fields of life there is only a fine line between yes and no statements. In management [8], [9] fields, managers have to face a lot of problems and their decisions can lead to several outcomes and consequences.

Uncertainty factor can make Boolean logic less precise, therefore Zadeh [10] created fuzzy logic. With the application of fuzzy logic and its values, real life can be modeled more precisely than by Boolean logic, because the validity of a statement is determined not only by using 0 or 1 values but by any values of the [0;1] interval [11]. And if the planning method is meticulous, it can result in savings in the company's budget, which can further lead to the company's survival and advantage in the market [12].

2.3. Combining critical path method with fuzzy logic

Critical path method is a very good tool in the planning phase of a project. But planning a project and real life is not always in accordance with each other: there can be a lot of unpredictable obstacles, e.g. uncertainty and constraints in the implementation stage of a project [13]. Therefore, there is a great potential in fuzzy logic to make project planning more thoughtful and realistic than conventional methods. Several papers were published in the topic of how fuzzy logic was implemented in many fields, like engineering, IT fields [13], thermal image processing [14], as well as articles were written about how fuzzy logic was added to CPM and led to useful results [15], [16], [17].

2.4. Decision making within a company

Regardless of a company's size or complexity, managers often have to face problems and decision-makings [18]. Some of these decisions seem trivial, but many of them require a great variety of information and a good decision-making tool to decide what alternative is worth choosing. For this purpose, a lot of multi-criteria decision-making techniques were invented, for instance Analytic Hierarchy Process (AHP) or Weighted Sum Model (WSM) [19]. In this model there are n decision criteria. Every single criterion has a weight, and it is assumed that the higher value a criterion gets, the more important the criteria is. Alternatives can be evaluated with the sum achieved by multiplying criteria values and their weights [19]:

$$A_i^{\text{weighted-score}} = \sum_{j=1}^n w_j a_{ij}, \quad (3)$$

where A_i is the total importance of the alternative; a_{ij} is the performance of the i -th alternative by j criteria. W_i is the weight assigned to i -th criteria.

Then, with the help of this multi-criteria model, decision makers can compare each alternative by their weighted score, and they can decide which alternative gives the best solution to that problem [17].

3. Material and methods

3.1. Product presentation

The manufacturing process we analyzed is an assembly process of an agricultural cultivator trailer. This machine helps limbering up the soil with needles and makes football courts suitable for playing as well as it can enliven other green areas by providing the soil with a better water drainage. Besides, this equipment can help to develop green areas by making grass stronger and denser. There is a great variety of this machine, and the demand for it is quite hectic, therefore the number of different products produced in a given period is low. Similar tools and equipment can also be used for assembling other machines. Considering these two features it can be stated that this assembly line works well in project manufacturing.

3.2. Data collection and processing

During the research at the company, 10-15 measurements were taken depending on the process steps. The next scene of the research was the Gemba, where the assembly line is located, and the researchers were able to get acquainted with the process while the duration of every single activity was timed. These measurements provided the basis for further work. Data analysis was made by MATLAB and Microsoft Excel with its Solver plug-in.

Steps of the research

- 1) All the data necessary for the research work at the company were collected. The duration of the data collection was 20 days;
- 2) The project net was drawn up;
- 3) The descriptive statistics of the collected data was prepared and the indicators and definitions that helped to compare the results were selected [6]:
 1. Critical path: the longest time path in the project;
 2. Total Process Time (TPT): total duration of the project from the first activity to the last;
 3. Total Slack Time (TST): maximum possible delay of an activity, which does not result in delay in the network;
 4. Free Slack Time (FST): maximum possible delay of an activity, which does not result in delay in the early start time of the next activity;
 5. Safety Slack Time (SST): maximum possible delay of an activity, which does not hinder the early start time of an activity;

- 4) The model's input were the time values that had been measured. These values were applied as inputs to create an operations research network model, the critical path of the process was calculated, as well as all the time slacks were analyzed;
- 5) Fuzzy-values were calculated according to literature reviews (triangular and sigmoid equations);
- 6) These fuzzy-values were applied in the critical path model and then it was examined whether the critical path had altered and whether the time slacks had changed;
- 7) The last step in the research was to compare all the model's indicators with the help of a decision making tool. The most suitable model was selected for the real life values with the application of weighted sum model.

3.3. Research goal

During the research the following question was determined:

Can the projects be made more reliable with the use of fuzzy-values?

At the same time the goal of the research was established:

It is possible to get closer to the project's real time value through fuzzy-CPM.

The reason for choosing this research goal was to make production more efficient and more cost-effective through precise predictions, because a more realistic planning can assist the company's management to create a more accurate business plan. Furthermore, the assembly line can prove to be more effective if a company is operated by a well-considered plan.

4. Case study

The examined process is an assembly line. The main process can be divided into two main parts: the first part is a pre-assembly, where the raw materials to be built into the main product are assembled (Nodes 1, 2, 3, 4). The second part is the main assembly process where raw materials and semi-processed products are built into one cultivator machine (From Node 5 to Node 15). The relationship between the activities can be seen in Fig. 1.

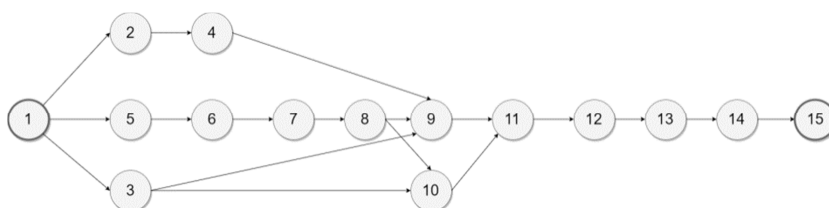


Fig. 1. Graphical representation of the assembly line

The next step in the research was to make a brief descriptive statistics from the measured activity times. At the request of the company, times were distorted, therefore the results can be seen in Time Measurement Unit (hereinafter tmu).

First of all the critical path was calculated. One full assembly process was measured from the first step to the last, and the values were applied to the model. This served as a basis for the further research.

After using the values in the model, we calculated the following results:

- Critical path: 1-5-6-7-8-9-11-12-13-14-15;
- Total process time: 12 142 tmu;
- Total slack time: 33 026 tmu;
- Free slack time: 19 838 tmu;
- Safety slack time: 9 122 tmu.

The company wanted to plan their production by using the mean values. *Table I* of the solver's sensitivity report revealed that the *critical path* was the following: 1-5-6-7-8-9-11-12-13-14-15.

Table I

Descriptive statistics of the measurement

Activity no.	Min. value	Max. value	Mean	Stand. dev.
2	557 tmu	719 tmu	641 tmu	50.6 tmu
3	420 tmu	450 tmu	435 tmu	13.0 tmu
4	130 tmu	178 tmu	145 tmu	9.8 tmu
5	509 tmu	1210 tmu	740 tmu	147.0 tmu
6	451 tmu	1037 tmu	685 tmu	113.5 tmu
7	203 tmu	352 tmu	275 tmu	44.3 tmu
8	290 tmu	565 tmu	415 tmu	55.1 tmu
9	4155 tmu	7000 tmu	5485 tmu	1028.9 tmu
10	768 tmu	916 tmu	835 tmu	22.0 tmu
11	810 tmu	907 tmu	855 tmu	23.0 tmu
12	820 tmu	1132 tmu	957 tmu	57.1 tmu
13	663 tmu	916 tmu	762 tmu	42.3 tmu
14	625 tmu	635 tmu	630 tmu	7.1 tmu
15	320 tmu	345 tmu	332 tmu	6.4 tmu

From other reports (limits and answer) the following times were calculated:

TPT: 11 136 tmu;

Free slack time: 19 078 tmu;

Total slack time: 28 066 tmu;

Safety slack time: 7 659 tmu.

4.1. CPM method complemented with fuzzy triangle numbers

The first method of creating fuzzy values was the Fuzzy Triangular Number (FTN) method of CPM. The following formula was applied to calculate FTN, which serves as an input for further calculation [16]:

(5)

The research group created the FTN-integrated model, and the following results were calculated: Critical path of the project was: *1-5-6-7-8-9-11-12-13-14-15*. It was the same as in the first model:

Free slack time: 19 576 tmu;
Safety slack time: 7 892 tmu.

4.2. CPM method complemented with fuzzy sigmoid function values

The applied function is the following:

(6)

Critical path of the project was: 1-5-6-7-8-9-11-12-13-14-15;

Free slack time: 19 838 tmu;
Safety slack time: 8 021 tmu.

Critical path of the project was: 1-5-6-7-8-9-11-12-13-14-15;

Free slack time: 21 356 tmu;
Safety slack time: 8 716 tmu.

4.3. Validation and decision making

Pollack Periodica 14, 2019, 1

the best, the importance of each criterion must be decided. There was a common agreement between the company's management and the research group in assigning weight to indicators, which is demonstrated in *Table II*.

Furthermore, the fit of each criterion was calculated by applying the following equation:

$$\left(1 - \frac{|\text{control model value} - \text{optimized model value}|}{\text{control model value}}\right) \cdot \text{indicator weight} . \quad (7)$$

The decision making matrix shows the final rank.

Table II

Weighted sum method weights

Indicators	Weights
Total process time	0.5
Total slack time	0.2
Free slack time	0.2
Safety slack time	0.1

The higher final value a method reaches; the better method it is. According to *Table III* considering the fit of predetermined indicators by real life value, the best method was the sigmoid method in which the y value is equal to 0.8.

Table III

Final rank with WSM

Method	TPT	TST	FST	SST	Final Value	Rank
Average	0.92	0.85	0.96	0.84	0.90	4.
Triangle	0.93	0.87	0.99	0.87	0.92	3.
Sig. (0.2)	0.94	0.89	1.00	0.88	0.93	2.
Sig. (0.8)	0.99	0.96	0.92	0.96	0.97	1.

If the company applies the best-fit fuzzy-value, the production planning can become more accurate than the result of the traditional network model. By using the better method, a company's planning can get closer by 7% to the real project process time.

Taking real life circumstances into account, the company in focus would be able to produce about 10 machines a week, but in their plan this number was 12. The company would have not been able to reach the production aimed at in its business plan.

5. Discussion

If the SME in the assembly industry cannot keep its predetermined partial-deadlines due to supplier's mistakes or to other reasons, the managers can get in a situation in

which they have to choose whether they change suppliers or standardize the assembly line. However, if it is not viable, the managers have to take the uncertainty factors into account and design their business plan in accordance with the available resources to make their production more efficient and profitable. In this paper, a case study is presented, where uncertainty factors were built into an operations research network model. Four fuzzy calculation types were compared to one another. On the basis of our case study, the results of the sigmoid fuzzy function proved to be the best, in which the following indicators were taken into account: total process time, free time slack, safety time slack and total time slack. As we assumed in the hypothesis, fuzzy-based production planning became more accurate and more realistic than the result of a traditional network model due to the factors of unpredictability of the human workforce and those of unforeseeable interruptions in the production.

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