Discussion with the paper 'Project costs planning in the conditions of uncertainty' by H. Štiková

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Abstract: In the paper, there is analysed one particular approach to the modelling uncertainty in the project management through an original version of the fuzzy CPM (Critical Path Method). First there is shown the relevance of using the fuzzy CPM in agriculture and the related branches and present the basics of the methods used. Then, there are described the imperfections of the work which is discussed and the impacts of the previously-published approach when applied in project management practice are emphasised. In the original paper, the author uses only the discrete fuzzy numbers for activity time durations which could be considered inappropriate for the time scheduling in project management. Consecutively, the direct application of the extension principle on the comparison of continuous durations could lead to the situation when both numbers can be greater than the second one with possibility equal to one. Moreover, the simple transformation of durations to the costs by linear equations with a positive slope does not respect the current project management theory and practice. Finally, the missing comparison of project fuzzy costs among individual variants of the project is calculated.

Key words: project management, fuzzy critical path method, project costs, project schedule

In this paper, we react on, discuss and cultivate the ideas presented in the paper 'Project costs planning in the conditions of uncertainty' by H. Štiková published in the Agricultural Economics, Vol. 58, No. 8, pp. 72–84 (Štiková 2012).

The paper deals with the cost analysis of projects with the vague activity durations. The author presents three project variants with slightly different networks and applies the fuzzy Critical Path Method (fuzzy CPM) developed by Mareš (2000). Based on that, she calculates the costs for the individual variants of the project using simple equations describing the relations between the time and costs of the activities.

The author applies her approach on agribusiness. It has been considered to be the area of applicability of the CPM almost since its invention (e.g. Cooke-Yarborough 1964). Coupland and Halyk (1969) used the CPM for analysing the hay harvesting systems. Based on their calculations, they have been able to optimize the systems for the least time required to complete the job. Colliver et al. (1978) used simulation techniques in the cooperation with the CPM method to determine the local optimal management procedures to minimize the energy cost in the grain solar drying systems. In particular, the CPM method helped them to find the local minimum energy cost mode that does not have a high potential for spoiling the corn for each time step throughout the drying period. Šubrt (2004) proposed the multiple criteria critical path method for the agricultural project management. Alongside the time analysis, such approach also considers the resource allocation. From the topical agriculture applications, we can present the work by Monjezi et al. (2012). They used the CPM method for the project scheduling and analysis in the case of the mechanized greenhouse construction project. They concentrated on reducing the time necessary for completing the project and calculating the economic benefits (cost savings) resulting from the shortening of the project.

On the other hand, the possibilities of the application of the standard CPM methods in agriculture are quite limited. More authors, see e.g. Boháčková (2014), describe the specifics of the agricultural sector. The most important are: long production cycles, the permanent uncertainty because of the biological character of the production, a strong dependence of the production on the environment and climatic conditions, the time misbalance between the supply (the outputs of the production processes) and

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demand (market situation) as well as between the costs (spent continuously) and revenues (after the products have been sold), etc.

Viewed by the project management in agriculture, the above-mentioned factors justify the application of the approaches working with uncertainty, i.e. the stochastic or fuzzy versions of the methods. Even in technical projects aimed at the agricultural waste processing all the way to producing the biomass energy (Khambalkar 2013), the energy production from biogas (Carrosio 2013) or the greenhouse production systems (Torrellas 2013), the uncertainty plays an important role in the project planning, scheduling and management.

Nevertheless, the fuzzy CPM or fuzzy PERT (Program Evaluation and Review Technique, see e.g. Malcolm et al. 1959) and the project cost analysis is a general problem with effect on multiple areas. In contrast with the common CPM and PERT, the fuzzy CPM is not unified as a result of some basic difficulties with fuzzy numbers. The fuzzy CPM exists in many versions.

Gagnon (2002) describes the fuzzy multimode resource-constrained project scheduling problem for the military purposes as the zero-one programming. Mareš (2000) develops the fuzzy CPM with the discrete membership function. Chanas et al. (2002) designed their approach based on fuzzy λ-cut of fuzzy numbers and distinguish the possibly and necessarily critical path. Fortin et al. (2010) describe the float time analysis on the level of activities with interval durations.

We aim this discussion at the disadvantages of the used approach and propositions which reflect the practicality of the proposed method. We also point out and clarify some imperfections in Štiková (2012) to support the argumentation used.

MATERIAL AND METHODS

Critical path method

The CPM is a fundamental and one of the most commonly-used methods in project management. According to the original work of Kelley and Walker (1959), the time analysis of the project by the common deterministic CPM can be simply described as follows:

A project is represented by a network graph $G(A, V)$, where V is a set of nodes (representing events) and arcs $A \subset V \times V$ represent activities which must be performed to finish the project. Each activity $(i, j) \in A$ is associated with the deterministic time duration t_{ij}. If $P(n)$ is a set of all paths from the first node 0 (kick-off of the project) to the last node n (end of the project) and the length of the path is the sum of the duration of the activities belonging to that path, then the critical path $p \in P(n)$ is the longest path from this set. Such path p denotes the total time necessary for the complete project.

However, the CPM method also provides more information. The fundamental part of the CPM allows us to determine the time reserves for all non-critical activities. Each node i has two time attributes, the earliest time t_i^0 and the latest event time t_i^1 (Kelley and Walker 1959: 162–163):

$$t_0^0 = 0$$

$$t_j^0 = max(t_i^0 + t_{ij}), 1 \le j \le n$$

$$t_n^1 = t_n^0$$

$$t_i^1 = mim(t_j^1 - t_{ij}), 0 \le i \le n-1 \quad (1)$$

Obviously, the activity could be delayed. The activity (i, j) that exceeds the duration t_{ij} is denoted as the "floater" and once each node has the earliest and the latest time, it is possible to calculate four basic float attributes for activities and events. These attributes express the time by which the duration of the activity can be prolonged with no impact on the complete project length, the beginning and/or other activity float attributes (Kelley and Walker 1959: 163):

– Total float = $t_j^1 - t_i^0 - t_{ij}$

– Free float = $t_j^0 - t_i^0 - t_{ij}$

– Independent float = $t_j^0 - t_i^1 - t_{ij}$

– Interfering float = $t_j^1 - t_i^0$

Concerning the definition of the critical path, it is clear that all critical activities have got all these attributes equal to zero.

The original CPM also contains basics of the cost analysis. Besides the normal activity duration, Kelley and Walker (1959) define crash times. Crash times represent the lower bounds for the activity duration. Such an activity crash leads to increasing of the cost of the activity, thus the project manager should find the adequate compromise between the duration and the cost of the project.

Fuzzy sets

Fuzzy sets arise from the effort to describe the real world which is characterised by vague definitions.

In terms of the sets' theory, the membership to the real worlds' sets is not precise (see e.g. Zadeh 1965 for origins or Dubois and Prade 2000 for basics of fuzzy sets).

The difference between the common (denoted as "crisp") sets and the fuzzy sets lies in the membership function (μ_A). In case of the crisp set (A), the element belongs to the set ($\mu_A = 1$), if it meets the conditions for the membership to the set A or it does not ($\mu_A = 0$), otherwise. In case of the fuzzy set ($\tilde{A}$), the element could belong to the set partially; here the membership function could be equal to any value from the interval [0, 1]. It holds (Zadeh 1965; Dubois and Prade 2000):

$\mu_{\tilde{A}}(x) = 0$; x surly does not belongs to $\tilde{A}$

$\mu_{\tilde{A}}(x) = 1$; x surly does belong to $\tilde{A}$

$0 < \mu_{\tilde{A}}(x) < 1$; x possibly does belong to $\tilde{A}$

The set $\{x \in \mathbf{R} | \mu_{\tilde{A}}(x) > 0\}$ is called support, $\{x \in \mathbf{R} | \mu_{\tilde{A}}(x) = 1\}$ is core or kernel (Mareš 2002; Dubois and Prade 2000).

The fuzzy sets allow us to express vague estimations like 'approximately' or 'approximately between'. Uncertainty at the beginning of the project and the related rough estimations of activities' durations are the reason for the fuzzy CPM formulation and application (see e.g. Han et al. 2006 or Gagnon 2002).

Even though it is possible to use the discrete membership function as Mareš (2000) or Štiková (2012), imperfect estimations and intervals with soft thresholds are commonly expressed as the fuzzy sets with the trapezoidal or triangular membership function (e.g. Dubois et al. 2003; Han et al. 2006; Sireesha and Shankar 2010).

The trapezoid fuzzy number $\tilde{A} = (a, b, c, d)$ is the subset of $\mathbf{R}$, with the following membership function:

$\mu_{\tilde{A}}(x) = 0$; for $x \le a$

$\mu_{\tilde{A}}(x) = \dfrac{x-a}{b-a}$ for $a \le x \le b$ (if and only if $a < b$)

$\mu_{\tilde{A}}(x) = 1$ for $b \le x \le c$

$$\mu_{\tilde{A}}(x) = \frac{d-x}{d-c} \quad \text{for } c \le x \le d \text{ (if and only if } c < d) \quad (3)$$

$\mu_{\tilde{A}}(x) = 0$; for $x \ge d$

$a \le b \le c \le d$

If $b = c$, the fuzzy number is denoted as triangular instead of trapezoidal. When $a = b$ or $c = d$, the bound is crisp and in case that both equalities happen, $\tilde{A}$ is not fuzzy set and describers the interval [c, d]. The fundaments of fuzzy logic as well as the operations with the fuzzy sets and fuzzy quantities are described e.g. in Dubois and Prade (2000) or Zhang and Liu (2006). In this paper, we use only the basic operations with the trapezoidal fuzzy numbers (TFN).

Let us denote $\tilde{A} = (a, b, c, d)$ and B = (p, q, r, s). Even though the basic extension principle (Zadeh 1965) would lead to a different result, the addition and subtraction with the TFN usually use (4) and (5) which lead again to the TFN:

$$\mu_{\tilde{A}\oplus\tilde{B}}(z) = sup\left[min\left(\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(y)\right): x, y \in \boldsymbol{R}, x + y = z\right] \approx (a+p, b+q, c+r, d+s) \quad (4)$$

$$\mu_{\tilde{A}\ominus\tilde{B}}(z) = sup\left[min\left(\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(y)\right): x, y \in \boldsymbol{R}, x - y = z\right] \approx (a-s, b-r, c-q, d-p) \quad (5)$$

The illustrative projects

All calculations are based on three variants of the simple project by Štiková (2012). The summary is presented in Figure 1 and Table 1.

RESULTS AND DISCUSSION

As we agree with Štiková (2012) and other authors, whose works were presented in the Introduction, we feel necessary to discuss a few ideas by Štiková (2012). The following text is not a criticism but a proposition how to make the methodology more useful and applicable in practical projects.

Extension principle and the CPM method

In general, it is impossible to simply apply the extension principle in the CPM method and in

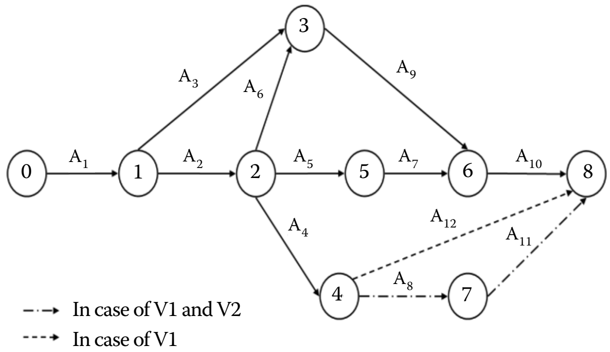

Figure 1. Project network (Štiková 2012: 77 and 81)

Table 1. Activities, fuzzy durations and cost functions (Štiková 2012: 77–81)

Activity	Membership function						Cost function
A_1	$\mu_1(2) = 0.2$	$\mu_1(3) = 0.1$	$\mu_1(4) = 0.5$	$\mu_1(5) = 0.2$		$\mu_1(t_1) = 0$ *elsewhere*	$c_1(t_1) = 1000 + 800t_1$
A_2	$\mu_2(3) = 0.4$	$\mu_2(4) = 1$	$\mu_2(2) = 0.3$			$\mu_2(t_2) = 0$ *elsewhere*	$c_2(t_2) = 1000t_2$
A_3		$\mu_3(7) = 1$	$\mu_3(8) = 0.5$	$\mu_3(9) = 0.2$		$\mu_3(t_3) = 0$ *elsewhere*	for $t_3 \leq 7$: $c_3(t_3) = 1000t_3$ for $t_3 > 7$: $c_3(t_3) = 1500t_3 -3500$
A_4		$\mu_4(6) = 0.1$	$\mu_4(7) = 1$	$\mu_4(8) = 0.3$	$\mu_4(9) = 0.1$	$\mu_4(t_4) = 0$ *elsewhere*	$c_4(t_4) = 800t_4$
A_5	$\mu_5(2) = 1$	$\mu_5(3) = 0.2$				$\mu_5(t_5) = 0$ *elsewhere*	$c_5(t_5) = 700t_5$
A_6		$\mu_6(5) = 0.3$	$\mu_6(6) = 1$	$\mu_6(7) = 0.4$	$\mu_6(8) = 0.1$	$\mu_6(t_6) = 0$ *elsewhere*	$c_6(t_6) = 500 + 700t_6$
A_7		$\mu_7(4) = 0.2$	$\mu_7(5) = 1$	$\mu_7(6) = 0.8$	$\mu_7(7) = 0.3$	$\mu_7(t_7) = 0$ *elsewhere*	$c_7(t_7) = 1000t_7$
A_8 in V_1	$\mu_8(2) = 0.3$	$\mu_8(3) = 1$	$\mu_8(4) = 0.8$	$\mu_8(5) = 0.6$	$\mu_8(6) = 0.1$	$\mu_8(t_8) = 0$ *elsewhere*	$c_8(t_8) = 800t_8$
A_8 in V_2		$\mu_8(5) = 0.2$	$\mu_8(6) = 1$	$\mu_8(7) = 0.4$	$\mu_8(8) = 0.1$	$\mu_8(t_8) = 0$ *elsewhere*	$c_8(t_8) = 500t_8$
A_9		$\mu_9(5) = 21$	$\mu_9(6) = 0.5$	$\mu_9(7) = 0.4$	$\mu_9(8) = 0.2$	$\mu_9(t_9) = 0$ *elsewhere*	for $t_9 \leq 6$: $c_9(t_9) = 1000t_9$ for $t_9 \leq 6$: $c_9(t_9) = 1000t_9 + 2000$
A_{10}	$\mu_{10}(3) = 0.1$	$\mu_{10}(4) = 1$	$\mu_{10}(5) = 0.5$	$\mu_{10}(6) = 0.1$		$\mu_{10}(t_{10}) = 0$ *elsewhere*	for $t_{10} \leq 5$: $c_{10}(t_{10}) = 1000t_{10}$ for $t_{10} \leq 5$: $c_{10}(t_{10}) = 1500t_{10} - 2500$
A_{11} in V_1		$\mu_{11}(4) = 1$		$\mu_{11}(6) = 0.7$		$\mu_{11}(t_{11}) = 0$ *elsewhere*	$c_{11}(t_{11}) = 900t_{11}$
A_{11} in V_2	$\mu_{11}(3) = 0.2$	$\mu_{11}(4 = 1$	$\mu_{11}(5) = 0.3$			$\mu_{11}(t_{11}) = 0$ *elsewhere*	$c_{11}(t_{11}) = 600t_{11}$
A_{12} in V_3		$\mu_{12}(6) = 0.6$	$\mu_{12}(7) = 1$	$\mu_{12}(8) = 0.2$		$\mu_{12}(t_{12}) = 0$ *elsewhere*	$c_{12}(t_{12}) = 1000t_{12}$

formulas (1) (see e.g. Mareš (1997) for discussion about problems with the generalisation of elementary crisp arithmetic operations to fuzzy numbers). Commonly $\tilde{A} \ominus \tilde{A} \neq 0$, the result of such an operation is 0-symmetric quantity $\mu_{\tilde{A}}(x) = \mu_{\tilde{A}}(-x)$, thus the simple extension of the CPM principles (as e.g. in Han et al. 2006) would lead to the situation with the possibility of the earlier latest event time rather than the earliest event time and negative values of some indicators. Mareš (2000) calculates the float time only for whole paths and negative float time is interpreted as the possibility of the criticality for non-critical paths. To deal with this problem, Soltani and Haji (2007) propose the methodology to obtain non-negative numbers only. Chanas et al. (2002) provide an example of an entirely different approach, using linear programming for L-R type of the fuzzy numbers (the TFN are of this type). Beside the possibly critical path, the authors also calculate the necessarily critical path. But again, this approach has a problematic application on activities. Concerning the analysis of float times on the level of activities has been the part of the CPM from its origins (Kelley and Walker 1959), it is hard to agree that the benefit of the fuzzy approach to the CPM is '... the information concerning not only the critical path, but also the grade of membership which another path may become critical with' (Štiková 2012: 78).

Štiková (2012) uses the fuzzy CPM as developed by Mareš (2000) with all its positives and negatives. The activities' duration is in this case denoted by the fuzzy number with the discrete membership function. As it has already been mentioned it is plausible to use triangle or trapezoidal fuzzy numbers to evaluate rough estimations and statements like 'approximately three' etc. (even Mareš (2002) uses such example for a different problem). Once durations or costs use trapezoidal fuzzy numbers, comparison used in Mareš (2000) and consequently in Štiková (2012) in (6) comes to be problematic. If the intersection of cores exists, than possibility that $\tilde{A} \geq \tilde{B}$ and also $\tilde{B} \geq \tilde{A}$ is always 1. To illustrate the troubles about ordering fuzzy quantities, the literature proposes more than forty methods (Wang and Kerre 2001, Sharafi et al. 2008). The second problem is the significantly increasing support of the fuzzy number (possible values of path length) which is already mentioned by Mareš (2000). This happens due to repeatedly using addition to calculate the duration of the path. Such increase also comprises consequences in the cost analysis. Even very small problem V1 in Štiková (2012: 77–79) brings the result of the possible project cost from less than 45 000 to more than 61 000 CZK. This is a really wide range even though the author uses cut $\tilde{C}^{0.3}$ (i.e. only costs with the possibility of 0.3 or higher are presented). The whole support of the fuzzy cost of the project V1 is wide interval 40 000–69 100 CZK.

Cost analysis

Another issue is the presentation of the costs. Štiková (2012) brings the simple transformation from time to the costs and then applies the simple fuzzy addition on all activities to obtain the cost of the project. The decision between different variants of realisation is a logical part of the planning phase of the project.

Realisation of the project is commonly described in terms of the project triangle – costs, time and scope of the project (Figure 2).

This triangle denotes three basic constraints with the opposite effect. Considering the line time-cost, the literature (see e.g. Bregman 2009) usually speaks about the trade-off. It is also possible to assume an increase of cost and time simultaneously; an example of such behaviour is the penalty for the construction delay. However, it usually comes during the project realisation. Strictly increasing costs of activities as function of its duration like in Štiková (2012) seems to be inappropriate for the proposed kind of analysis.

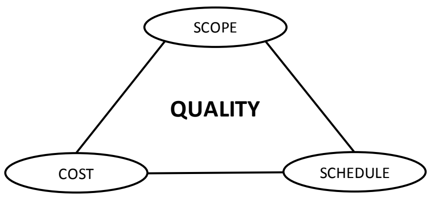

Figure 2. The project management triangle (Lewis 2005)

Table 2: Comparison of the project fuzzy costs

	$\leq\tilde{C}_1$	$\leq\tilde{C}_2$	$\leq\tilde{C}_3$	$\mu_{Ch}(\tilde{C}_i)$	Lower bound	Upper bound
$\tilde{C}_1$	1	0.8	1	0.8	40 000	69 100
$\tilde{C}_2$	1	1	1	1	39 100	66 700
$\tilde{C}_3$	0.8	0.6	1	0.6	40 800	66 900

Despite Štiková (2012) provides a full time analysis based on Mareš (2000), the analysis of the project costs is quite limited. Three variants are compared only on the basis of the costs with the possibility grade equal to 1. With the assumption of discrete membership functions, it is possible to use a similar formula as for durations (Mareš 2000; Štiková 2012) but with the opposite relation (6). Again, the project is the cheapest with the grade of possibility. Let $\tilde{C}_i$ denote the fuzzy total cost of the project variant V_i and the set of all the variants' costs is $\boldsymbol{C}$, than the possibility of being the cheapest μ_{Ch} variant is calculated from (7).

$$\mu_{\leq}(\tilde{C}_i, \tilde{C}_j) = sup\left[min\left(\mu_{\tilde{C}_i}(x), \mu_{\tilde{C}_j}(y)\right): x, y \in \boldsymbol{R}, x \leq y, i \neq j\right] \tag{6}$$

$$\mu_{Ch}(\tilde{C}_i) = min\left[\mu_{\leq}(\tilde{C}_i, \tilde{C}_j): \tilde{C}_j \in \boldsymbol{C}\right] \tag{7}$$

Table 2 contains the missing part of the analysis of the project cost. As in Štiková (2012), the variant V_2 is the cheapest with the possibility grade $\mu_{Ch}(\tilde{C}_2) = 1$, but the analysis provides also the possibility of being the cheapest for other projects (which is even quite high). The last two columns in Table 2 show the already mentioned problems with the growing support of fuzzy number. The range between the lower and upper bound represents more than 64% for possibly the most expensive V_3 and more 70% for other two variants.

CONLUSIONS

In this paper, we stress the disadvantages of the used approach by Mareš (2000) and the basic problems of the generalization of the CPM formulas to fuzzy numbers. The simple addition of the fuzzy numbers results in very wide intervals of the possible values, which decrease the practical usefulness of the proposed approach. Also the discrete membership function for the activities' durations seems to be a too strict condition.

Cost expression as increasing with the activity duration is against the basic project management point of view. Such behaviour can be part of the realization as a penalty for delay. However, the proposed cost analysis is logical in the planning part of the project. Moreover, the penalty should be interconnected with the total project duration and not with the single activities. In the end of the paper, we calculate the possibility of being the cheapest for each project variant, which we feel is the missing part in the original Štiková (2012).

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