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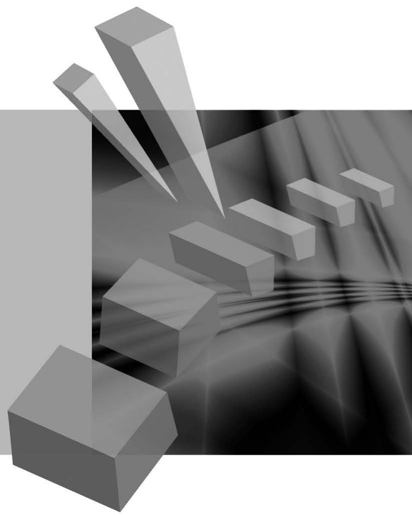

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Zastosowanie badań operacyjnych
Zarządzanie projektami, decyzje finansowe, logistyka ISSN 1899-3192

Marek Janczura, Dorota Kuchta
Technical University in Wrocław

PROACTIVE AND REACTIVE SCHEDULING IN PRACTICE

Summary: The paper develops a method proposed earlier of proactive and reactive scheduling [Janczura, Kuchta 2011], in which fuzzy task durations are used, but the resources have to plan their work according to a crisp schedule. In the proposed method for determining the crisp representations three strategies are used. The first strategy is based on the average. The other two are based on optimistic or pessimistic time estimation given by an expert. Human resources are allocated according to the strategy chosen by the project manager. This article proposes an algorithm to support the decision maker in choosing the best strategy to achieve the shortest total duration of the project, where the decision maker chooses a safety level for the project. To illustrate the proposed approach, the algorithm was tested on the data from a real project.

Keywords: project management, proactive and reactive scheduling, resource constraints, fuzzy numbers.

1. Introduction

It is common knowledge that projects have to be planned and controlled. However, a review of scientific literature as well as interviews among project management practitioners show clearly that both in the research and in practice the greatest emphasis is put on the planning phase. But it is also common knowledge that all the projects are linked to a smaller or greater degree to risk and uncertainty, which often makes the initial plans considerably or almost completely irrelevant to the real project situations. Thus there is no excuse in neglecting the control of project realization. We can even say that in some cases the control phase is more important that the planning phase – it does happen, especially in the initial period of project realization, that the "truth" about the project is revealed – the "truth" which remained hidden before the project was actually started. It is often only once the project is started that some project stakeholders reveal their true attitude towards the project, that some humans and also material resources reveal their actual work speed, efficiency and quality, that some suppliers and subcontractors show their real willingness and ability to cooperate etc. Thus it is often only during the project realization, usually at its very beginning or at the beginning of a project phase (when new resource or new stakeholder enters into the game) that we can actually plan the project future, but always being aware that even those late plans may be turned upside down by the uncertainty, human and technical problems and other phenomena not known or not taken into account before.

That is why the present paper is devoted to proactive, but above all the reactive scheduling, i.e. scheduling during the project realization, in reaction to what has happened in the project up to the control moment. As to the literature review in this area, first of all we have to mention the work of [Calhoun et al. 2002] and [Vonder et al. 2006, 2007]. They consider in control moments during the project realization the unfinished project part and schedule it according to the preferences of the decision maker. The preferences may be expressed e.g. as follows:

a) the project completion time forecast in the control moment should be minimized,

b) selected activities, whose resources will be available only in a certain period of time (to get them outside this period would be difficult and cost a lot) should not be moved, if possible, or should be moved very little, even if this increases the project forecast completion time,

c) the assignment of human resources to activities as well as the order in which each human resource type will execute them should remain unchanged (because a certain learning process has been planned which cannot be changed), even if this increases the project forecast completion time.

These approaches show that the reactive scheduling has to be performed in cooperation with the decision maker. In each control moment all relevant information has to be gathered, as well as the current preferences of all the project stakeholders. The reactive scheduling process cannot be made completely automatic, because the current situation and the current project stakeholders preferences may change continuously. However, having in mind the notorious lack of time during the realization of almost every project, we have to design such a system in which the decision maker would be able to give short answers. In our earlier paper [Janczura, Kuchta 2011] we already proposed a system in which the decision maker chooses his pessimism/optimism level as to the activities duration. In the present paper we extend the interaction process with the decision maker in the reactive scheduling in introducing the notion of a project safety degree the decision maker is asked about and which determines the outcome of the scheduling algorithm that we also propose here.

In both our earlier papers linked to proactive and reactive scheduling [Janczura, Kuchta 2010, 2011] we used a tool which is widely applied to model risk and uncertainty in projects [e.g Chanas, Zielinski 2001], but in project scheduling in the planning phase. This tool are fuzzy numbers. We have used it also in reactive scheduling, because, as we emphasized above, in the project realization phase risk and uncertainty do not disappear, are usually very significant in the initial period of project realization and often remain such till the end. We also here use this tool.

The structure of the paper is as follows. In Section 2 we give basic information about fuzzy numbers, about the notation used here for project representation, and about the proactive reactive scheduling generally. In Section 3 we introduce our new approach for selecting the appropriate resource allocation strategy at the project level, while in Section 4 we present the use case of this method in the real project. Section 5, which is the last one, contains conclusions.

2. Background

2.1. Fuzziness as a measurement of uncertainty

Fuzzy numbers represent a value which we know for the moment only approximately. Each fuzzy number is uniquely determined by its membership function. There are several types of fuzzy numbers, here we restrain ourselves to so called trapezoidal fuzzy numbers [Kuchta 2001]:

Definition 1: A trapezoidal fuzzy number $\tilde{A} = (l, \underline{a}, \overline{a}, u)$, where $l, u > 0$, $\underline{a} \leq \overline{a}$ is represented by a membership function $m_A : \mathbb{R} \to [0,1]$ such that

$$m_A(x) = \begin{cases} 1 \text{ for } x \epsilon [\underline{a}, \overline{a}], \\ 1 - \frac{\underline{a}-x}{l} \text{ for } x \epsilon [\underline{a} - l, \underline{a}], \\ 1 + \frac{\overline{a}-x}{u} \text{ for } x \epsilon [\overline{a}, \overline{a} + u], \\ 0 \text{ otherwise.} \end{cases} \quad (1)$$

The membership function of the fuzzy number $\tilde{A} = (l, \underline{a}, \overline{a}, u)$ is illustrated in Figure 1.

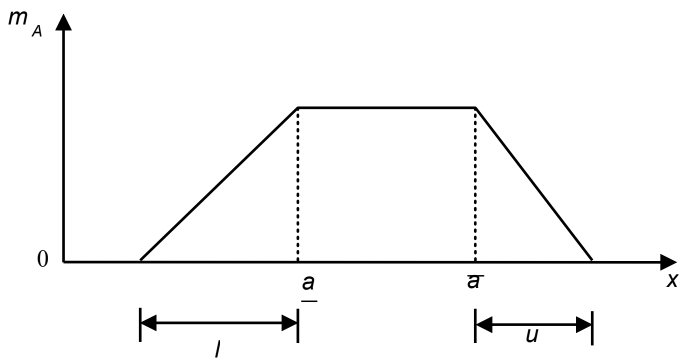

Figure 1. Trapezoidal fuzzy number $\tilde{A} = (l, \underline{a}, \overline{a}, u)$

Source: own work.

A trapezoidal fuzzy number $\tilde{A} = (l, \underline{a}, \overline{a}, u)$ represents a magnitude A whose crisp, exact value may be known only in the future. For the moment we can only estimate the possibility degrees of various values to be the actual value of A, given by the function m_A. We think that vales belonging to the interval $[\underline{a}, \overline{a}]$ may become the actual values of A with the possibility degree 1. The values from the intervals $(\underline{a} - l, \underline{a})$ and $(\overline{a}, \overline{a} + u)$ may become the actual values of A with a positive possibility degree, the smaller the bigger the distance from the interval $[\underline{a}, \overline{a}]$. The values outside the interval $(\underline{a} - l, \overline{a} + u)$ may become the actual values of A with the possibility degree 0. The parameters l, u represent the risk and uncertainty – if they are big, the uncertainty linked to the magnitude A is high.

An important notion linked to a fuzzy number $\tilde{A} = (l, \underline{a}, \overline{a}, u)$ is that of the α −cut, denoted as A^α, $\alpha \epsilon [0,1]$. It is the set of all those values which may become the actual value of A with a possibility degree equal or greater than α:

Definition 2: The α −cut of a trapezoidal fuzzy number $\tilde{A} = (l, \underline{a}, \overline{a}, u)$, denoted as A^α, $\alpha \epsilon [0,1]$, is defined as:

$$A^\alpha = \{x : m_A(x) \geq \alpha\}. \tag{2}$$

It is easy to show that for each trapezoidal number $\tilde{A} = (l, \underline{a}, \overline{a}, u)$ all its α −cuts are closed connected intervals, we can thus introduce the notation $A^\alpha = [\underline{a}^\alpha, \overline{a}^\alpha]$, $\alpha \epsilon [0,1]$.

As far as addition of fuzzy numbers is concerned, for trapezoidal fuzzy numbers it is defined as follows:

Definition 3: Let $\tilde{A} = (l_A, \underline{a}, \overline{a}, u_A)$ and $\tilde{B} = (l_B, \underline{b}, \overline{b}, u_B)$ be two trapezoidal fuzzy numbers. Their sum is also a trapezoidal fuzzy number, defined as follows:

$$\tilde{A} + \tilde{B} = (l_A + l_B, \underline{a} + \underline{b}, \overline{a} + \overline{b}, u_A + u_B). \tag{3}$$

We can notice that the uncertainty of two fuzzy numbers is accumulated in their sum.

Let us now pass to some basic notions concerning project representation.

2.2. Project representation

In this paper we treat a project as a list of activities among which only one precedence relation is defined: the "finish-to–relation", meaning that the predecessor activity of this relation has to be completed before or at the latest when the successor activity is started. Such projects can be represented as networks in which the activities are arcs, where the set of all the arcs will be denoted as E. Thus each activity is defined as an arc $(i, j), i, j = 1, \ldots N$, where N is the number of nodes, node 1 represents the start of the project (arcs $(1, i) \epsilon E$ represent activities which have no predecessors) and node N the end of the project (arcs $(i, N) \epsilon E$ represent activities which have no successors).

Each activity has several attributes. In our case the most important attribute is the planned duration, denoted as t_{ij} in case this estimation is exact (crisp) and $\tilde{T}_{ij} = = \left(l_{ij}, \underline{t}_{ij}, \overline{t}_{ij}, u_{ij}\right)$ in case the estimation is a trapezoidal fuzzy number.

Using appropriate scheduling methods (a review can be found in [Kuchta 2011]), we can work out a feasible schedule (thus a schedule respecting the activities precedence relations and the resource availability constrains for the project) and estimate the expected project completion time. If the estimations of task activities are fuzzy, also the project estimated completion time will be fuzzy (because of Definition 3).

Fuzzy project duration estimate is important to measure the risk of the exceeding project deadline, however, the project resource have to work according to a crisp plan. In our previous paper [Janczura, Kuchta 2011] we suggested how to construct such a crisp schedule for resource on the basis of project manager preferences (optimism/pessimism degree).

However, this process – performed in the project planning phase – cannot be left unrepeated. This is the subject of the next subsection.

2.3. Proactive and reactive scheduling

Proactive scheduling can be defined as a scheduling which in the project planning phase attempts, as much as possible, to protect the project schedule against undesired time problems during the project realization. The outcome of the project planning phase are among others estimations described in Section 2.2

Reactive scheduling can be defined as updating/modifying the estimations described in subsection 2.2 in subsequent control moments during the project realization on the basis of the information about the project execution and its whole context and environment known in the very control moment. Knowing how the project has been going so far and what has changed in the knowledge about its stakeholders, technical, social and political circumstances we re-estimate the activities duration, maybe also the resource requirements and availability and on this basis we re-estimate the project completion time.

In our previous paper [Janczura, Kuchta 2010] we proposed how to update the fuzzy duration estimates $\tilde{T}_{ij} = \left(l_{ij}, \underline{t}_{ij}, \overline{t}_{ij}, u_{ij}\right)$ of unfinished activities on the basis of the information of the activity execution so far. Then we re-estimate the project completion time, also in the form of a fuzzy number. Also, as in the planning phase, the resources have to get a crisp plan to work with. We can apply here the procedure mentioned in subsection 2.2 [Janczura, Kuchta 2011].

3. Choosing an appropriate strategy for resources allocation

To allocate resources in the real project it is required to have a crisp schedule. In other words we need to make defuzzyfication for fuzzy activity times. One of the common methods is to calculate average number – Yager Index [Chen, Hwang

1997]. For this method of computing crisp numbers for tasks in a project we will use notion of "average strategy". In this section two other strategies are described as well. This concept of choosing different strategies for resource allocation was presented in details in [Janczura, Kuchta 2011]. Next we show a new algorithm for selecting the best strategies for each task in order to meet some general assumptions for the whole project specified by the project manager. One of the assumptions might be minimization of the total duration time of the project.

In the last paragraph we define some measures to compare efficiency of this new approach for selecting different strategy for each task with the standard approach based on average value.

3.1. Three different strategies

Resource allocation in the real project depends on the strategy assumed by the project manager. It helps to find the proper time for resource reservation in the given task. We can assume that each task or group of tasks may have its own strategy in a given moment of the project realization (i.e. all tasks on critical path).

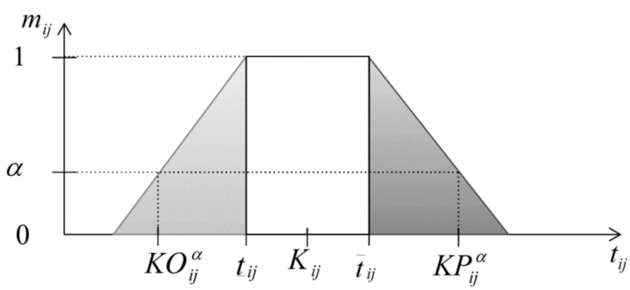

Figure 2. Possible deterministic values of time for an activity (i, j) for average K_{ij}, optimistic KO_{ij}^{α} and pessimistic KP_{ij}^{α} strategy

Source: own work.

The starting point for this calculation is fuzzy activity time. We defined [Janczura, Kuchta 2011] three different strategies:

1) Average strategy – resource allocation for the time K_{ij} – which is an average number from the fuzzy number that can be calculated as Yager index.

2) Optimistic strategy – resource allocation for the time KO_{ij}^{α} where:

$$KO_{ij}^{\alpha} = \alpha\, l_{ij} + \underline{t}_{ij} - l_{ij}\,. \tag{4}$$

3) Pessimistic strategy – resource allocation for the time KP_{ij}^{α} where:

$$KP_{ij}^{\alpha} = \overline{t}_{ij} + u_{ij} - \alpha u_{ij}\,. \tag{5}$$

Values KO_{ij}^{α} and KP_{ij}^{α} are calculated based on the membership function (see 1). Parameter α (see Definition 2) is valuated between 0 and 1 and used to graduate pessimistic and optimistic approach.

The decision maker may prefer the following approaches:

1) $\alpha = 0$, taking care into consideration all risk and uncertainty for the given activity (I, j).

2) $\alpha = 1$, ignoring uncertainty and risk in time estimation for the given activity (i, j).

3) $\alpha \in (0, 1)$, indirect approach to the two other approaches mentioned above.

In this paper we assume the selection of $\alpha = 0$.

3.2. Task security level

We propose to calculate for each task a security level – TSL_{ij}^{α}, where

$$TSL_{ij}^{\alpha} \in [0,1], \tag{6}$$

$$TSL_{ij}^{\alpha} \geq \frac{KO_{ij}^{\alpha}}{KP_{ij}^{\alpha}}. \tag{7}$$

TSL_{ij}^{α} defines a portion of the most pessimistic value KP^{α}. For instance, we can assume that for a given task (i, j) the TSL_{ij}^{α} is equal to 80%, what means that in our calculation we assume 80% security level for the given task. In the other words TSL_{ij}^{α} level illustrates how close or far we are to the pessimistic estimation that we assumed as the fully secure one.

To determine the real time for an activity (i, j) we define the following:

$$KSL_{ij}^{\alpha} = TSL_{ij}^{\alpha} * KP_{ij}^{\alpha}, \tag{8}$$

where KSL_{ij}^{α} is the crisp time for an activity (i, j) at a given task security level TSL_{ij}^{α}. Continuing previously mentioned example, where $TSL_{ij}^{\alpha} = 80\%$, we can assume that $KP_{ij}^{\alpha} = 6$. Then the corresponding crisp time for an activity (i, j) is as follows:

$$KSL_{ij}^{\alpha} = 80\% * KP_{ij}^{\alpha} = 80\% * 6 = 4{,}8.$$

The KSL_{ij}^{α} is evaluated from KO_{ij}^{α} to KP_{ij}^{α} (see Figure 4). For higher security level we are closer to the pessimistic estimations and for a lower security level to the optimistic estimations.

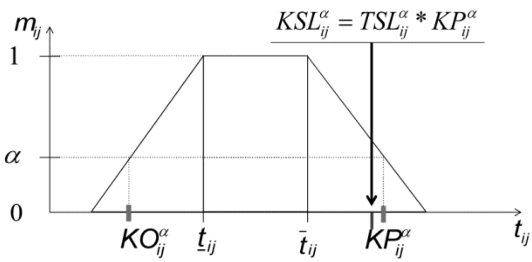

Figure 3. Possible deterministic values of time for an activity (I, j) based on task security level – TSL_{ij}^{α}.

Source: own work.

3.3. Project security level

In the previous chapter we have described a task security level and the corresponding crisp time evaluation. For the whole project perspective we define the project security level as:

$$PSL_{ij}^{\alpha} = \frac{\sum_{ij} KSL_{ij}^{\alpha}}{\sum_{ij} KP_{ij}^{\alpha}}, \tag{9}$$

where PSL_{ij}^{α} is the ratio of a sum of all activities times corresponding to its security level and a sum of all pessimistic time estimations. Then PSL_{ij}^{α} is evaluated in the range [0.1].

It is important to mention that for the given project security level we may have different strategies: average, pessimistic and optimistic as well.

3.4. Finding KSL

It is obvious that in a very complicated project it seems to be impossible for a project manager to decide about the proper security level for each task. Nevertheless, our approach assume interaction with the project manager according to the following rules:

- project manager defines at least the security level for the whole project – PSL^{α} and the value of parameter α,
- project manager may define some constraints for a specific task or for a group of tasks (i.e. critical path). At this step it is possible to choose manually a strategy at the given task level,
- our algorithm computes the best, at the given constraints (minimization of the total duration time of the project), security levels for all tasks. If not specified by the project manager, the strategy at a given task level is automatically chosen (typically all strategies are taken into account).

In general, the aim of this research is to develop an algorithm that will minimize the total duration time of the project (see eq. (10)) and, as a by-product, find an appropriate strategy for resources allocation.

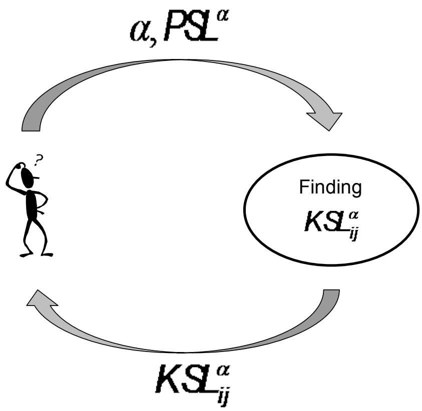

Figure 4. Data flow between project manager and algorithm of computing task security levels

Source: own work.

For the project manager it is important to see how all tasks security levels affect the average security level for the whole project. From his perspective it seems to be important to control PSL^{α} at a given level. Our approach provides the project manager with such a possibility. In the following we will call such an approach the project security level (PSL^{α}) strategy.

A problem of finding the proper security level for each task with respect to the given project security level is defined as follows:

$$\sum_{ij} KSL_{ij}^{\alpha} \to \min, (i, j) \in C, \tag{10}$$

where C is the set of all activities for which we want to minimize duration times (i.e. critical path). We want to minimize tasks duration times within the given set C with respect to the following constraints:

$$PSL_{ij}^{\alpha} \geq \frac{\sum_{ij} KSL_{ij}^{\alpha}}{\sum_{ij} KP_{ij}^{\alpha}}, \tag{11}$$

$$KSL_{ij}^{\alpha} \geq KO_{ij}^{\alpha} * lTSL_{ij}^{\alpha},\ lTSL \geq 1, \tag{12}$$

$$KSL_{ij}^{\alpha} \leq KP_{ij}^{\alpha} * uTSL_{ij}^{\alpha},\ uTSL \leq 1, \tag{13}$$

$$lTSL_{ij}^{\alpha} * KO_{ij}^{\alpha} \leq uTSL_{ij}^{\alpha} * KP_{ij}^{\alpha}. \quad (14)$$

$lTSL_{ij}^{\alpha}$ and $uTSL_{ij}^{\alpha}$ are additional parameters that can be used to narrow the range of possible values for time duration (12, 13, 14). One of the possible applications might be securing all activities on the critical path with the lower constraint $lTSL_{ij}^{\alpha}$. On the other hand, it is possible for a project manager to set manually a strategy at the task level. Otherwise, an algorithm will search for a value KSL_{ij}^{α} within the interval $[KO_{ij}^{\alpha}, KP_{ij}^{\alpha}]$ for a given α level. Thus, the value KSL_{ij}^{α} will be automatically selected among three strategies for resource allocation.

3.5. KSL measurements

In the following chapter we propose two measures to evaluate accuracy of the selected approach. The measures are based on a calculation of a deviation from the real values, so they require project completion. We measure the ratio of the sum of all activities estimation based on the given strategy (*K* or *PSL*) to the sum of real activities duration. Then we can compare the obtained factors *pK* (see 15) and *pKSL* (see 16) defining error measurement for an average and the project security level method, respectively.

$$pK = \frac{\sum_{ij} K_{ij}^{\alpha}}{\sum_{ij} KR_{ij}^{\alpha}}, \quad (15)$$

$$pKSL = \frac{\sum_{ij} KSL_{ij}^{\alpha}}{\sum_{ij} KR_{ij}^{\alpha}}. \quad (16)$$

The above proposed measures for both approaches can be computed for different stages in the project to see when and which method is more accurate.

4. Example

In this chapter we will present a simulation study of our algorithm within the real project from one if IT companies. First, we will describe, how the activity estimations were transformed to the fuzzy model from the interview with an expert. Then, in the next part regarding the planning phase, we will present calculations of crisp values for the average *K* and the *PSL* method for fuzzy estimations. In this section we will compute also deviations for both methods from the real durations.

In the final section of this chapter we will compare the different approaches with the real activities times during the project realization. We will illustrate a latency tendency for a group of tasks. Then, the importance of the first tasks updates during project realization will be presented.

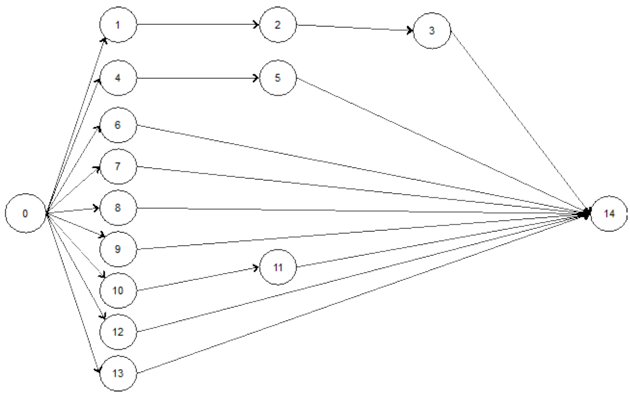

Figure 5. Real project structure

Source: own work.

On the network diagram (see Figure5) all activities in the project and corresponding dependencies are presented. In reality all tasks have been realized with many pauses and preceding relations have not been fulfilled. In this research we assumed the following:

- all tasks have been realized in parallel,
- we do not calculate pauses in tasks realization.

4.1. Mapping answers from decision makers to the model

We have tested our model with data from the real project. An expert was estimating activities time durations based on the questionnaire (see Table1) with the following questions:

– What is the range for certain activities duration (highest chance of realization)?
– What is the most optimistic time duration (low chance of realization)?
– What is the most pessimistic time duration (low chance of realization)?

Table 1. Questionnaire for activity time estimation

Task (I, j)	Date	Hour	Remaining time (days)			
			no less than	certain		no longer than
				from	to	
(4, 5)	-	-	2	3	4	5
(4, 5)	11-03-31	11:00	4	5	6	7

Source: own work.

These values can be easily transferred to the fuzzy model using membership function (see 1). For the activity (4, 5) listed in the table (see Table 2) the fuzzy representation looks as follows:

Table 2. Fuzzy time representation for the activity (4, 5)

Task (*I, j*)	Date	Hour	$\underline{t}_{ij}$	$\overline{t}_{ij}$	l_{ij}	u_{ij}
(4, 5)	–	–	3	4	1	1
(4, 5)	11-03-31	11:00	5,09	6,66	1,57	1,57

Source: own work.

For each tasks first estimation (Date='–' and Hour='–') comes from the planning phase. Then, after the project started, data have been updated during project realization two times a day. The real length of the tasks varies from 2 to 14 days.

4.2. Time estimation – planning phase

4.2.1. Schedule construction

All tasks are represented by their fuzzy activity duration and crisp average value (K_{ij}).

Then during the project realization the schedule is being updated at the stages (two per day) for each task in the following order:

1. Expert estimates new remaining times (see Table3).
2. Algorithm calculates:
   - 2.1. Experts estimate into the fuzzy model.
   - 2.2. Average crisp value K_{ij} for each task.
   - 2.3. Latency/acceleration factors.
3. For some stages (0 and 3) we have also calculated the crisp activity durations for all tasks based on the given project security level PSL^{α} to check an accuracy of this approach in comparison with the average method (K_{ij}). For the KSL_{ij}^{α} computation we assumed the following:
   - 3.1. $PSL^{\alpha} = 95\%$.
   - 3.2. $\alpha = 0$.
   - 3.3. All tasks are realized in parallel.
   - 3.4. No tasks dependencies.

4.2.2. First estimation

The stage number 0 corresponds to the first estimation for all tasks in the project (before the project realization phase). We have assumed the project security level $PSL^{\alpha} = 95\%$.

Table 3. Duration time estimation for all activities in the planning phase

Task (i, j)	Stage	$\underline{t}_{ij}$	$\overline{t}_{ij}$	I_{ij}	u_{ij}	K_{ij}	KSL_{ij}^{o}	KR_{ij}
(0, 1)	0	1	1	0	1	1.25	2	4.25
(1, 2)	0	2	2	1	1	2	3	3.25
(2, 3)	0	1	1	0	1	1.25	2	2.25
(0, 4)	0	2	2	1	1	2	3	3.25
(4, 5)	0	3	4	1	1	3.5	5	8.63
(0, 6)	0	4	5	1	1	4.5	6	3.88
(0, 7)	0	1	1	0	1	1.25	1	1.25
(0, 8)	0	3	4	0	1	3.75	5	2.88
(0, 9)	0	1	1	0	1	1.25	1	1.25
(10, 11)	0	2	3	0	1	2.75	4	2.88
(0, 11)	0	3	4	0	1	3.75	5	3.88
(0, 12)	0	4	5	0	1	4.75	6	5.25
(0, 13)	0	4	5	0	1	4.75	5.45	14

Source: own work.

Table 3 presents fuzzy estimations (col. 3-6) for all activities at the stage = 0 before the project realization. All fuzzy parameters were transformed from the expert estimations. Three last columns contain total duration time for each activity (I, j) respectively:

a) K_{ij} – crisp average time,

b) KSL_{ij}^{o} crisp time estimation based on the given project security level (PSL^{α} = 95%),

c) KR_{ij} – real time duration.

4.2.3. Evaluation of PSL^{α} and K_{ij} method

Considering the real activity times we are able to evaluate an accuracy of the proposed method. Deviations for both methods (K_{ij}, PSL^{α}) from the real activity durations equal to 85% and 65% respectively (see Table 4).

Table 4. Compliance factors for method K_{ij} and PSL^{α} at the planning level with real activities duration

Stage	PSL^{0}	pK	$pKSL$
0	95%	65%	85%

Source: own work.

It seems that, for such a kind of projects, it is better to assume more pessimistic scenario for activity time estimations. The higher security level the more pessimistic rather than optimistic values are considered.

4.3. Time estimation – realization phase

During the project realization each task has been updated two times a day. From the project realization phase we have selected stage number 3. Taking into account our assumption that all tasks have been realized in parallel, stages are the same points in time for all activities. The corresponding data are collected in Table 5.

Table 5. Duration time estimation for all activities at the third stage

Task (i, j)	Stage	$\underline{t}_{ij}$	$\overline{t}_{ij}$	I_{ij}	u_{ij}	K_{ij}	KSL^{o}_{ij}	KR_{ij}
(0, 1)	3	4.02	4.02	0.00	1.42	4.38	5.44	4.25
(1, 2)	3	4.13	4.13	0.91	0.91	4.13	5.03	3.25
(2, 3)	3	2.50	2.50	0.00	0.48	2.63	2.99	2.25
(0, 4)	3	4.13	4.13	0.93	0.93	4.13	5.05	3.25
(4, 5)	3	6.01	7.24	1.24	1.24	6.63	8.48	8.63
(0, 6)	3	4.80	5.45	0.64	0.64	5.13	6.09	3.88
(0, 7)	3	3.04	3.32	0.00	0.27	3.25	3.59	2.88
(0, 8)	3	3.49	3.84	0.00	0.35	3.75	4.18	2.88
(0, 9)	3	3.98	4.34	0.00	0.37	4.25	4.10	3.88
(10, 11)	3	4.45	4.85	0.00	0.40	4.75	4.45	5.25
(0, 11)	3	5.08	5.81	0.00	0.73	5.63	5.08	14

Source: own work.

4.3.1. Comparison between PSL^{α} and K_{ij} method

Deviations for both methods are presented in Table 6. At the considered stage (3) the PSL^{α} = 95% gives the best and most accurate estimation to the real durations of all activities in the project.

Table 6. Compliance factors for method K_{ij} and PSL^{α} during project realization (stage 3) with real activities duration

Stage	PSL^{α}	pK	$pKSL$
3	95%	89%	100%

Source: own work.

Although at the whole project level the method based on PSL^{α} gives more accurate estimations than the average method, it must not be the same case at the task level.

Let us consider two tasks from Table 5, task (4, 5) and (0, 6) respectively.

For task (4, 5), the real duration is equal to 8.63 days. The method based on PSL^{α} has deviation in duration estimation about 1% as $KSL^{0}_{(4,5)}$ = 8.48 days. The average method with $K_{(4,5)}$ = 6.63 days deviates more than 20% from the real value.

On the other hand, for the task (0, 6) we have the opposite situation. The $KSL^{0}_{(0,6)}$ = 6.09 days deviates about 56% from the real value (3.88 days), while the average method with $K_{(0,6)}$= 5,13 deviates about 32%.

It may happen that some tasks will be overestimated. This is a consequence of the fact that the method based on PSL^{α} takes into consideration all tasks in the project to achieve the best resultant for all of them.

4.3.2. Latency tendency

In this section we present the trend in latency for most of the tasks in the given project. The graph (see Figure 6) illustrates the relation of the real realization of the activity (I, j) at time k to the planned realization of the activity (I, j) at time k defined as $pr^{k}_{ij} \,/\, pp^{k}_{ij}$. Acceleration and latency factors are described in detail in [Janczura, Kuchta 2010].

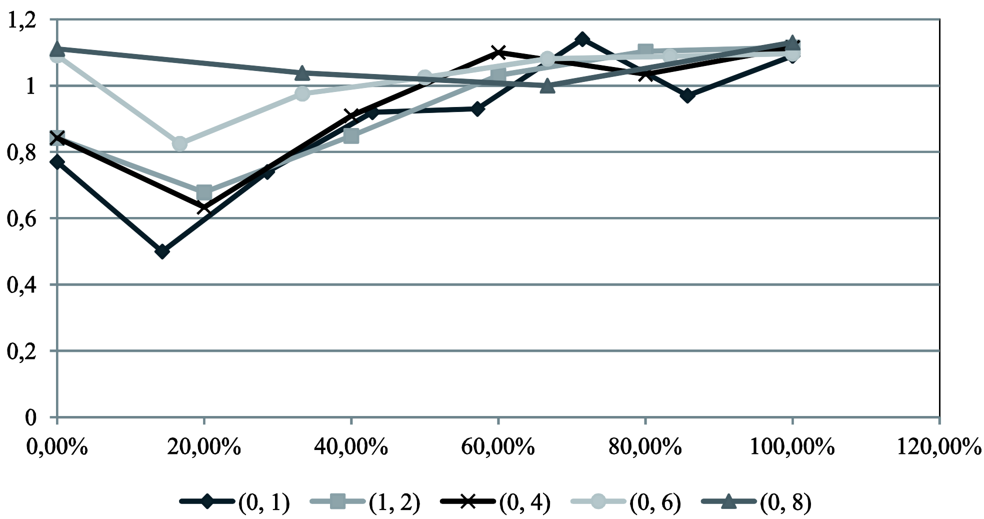

Figure 6. Latency/acceleration graph for the selected activities in the project

Source: own work.

In the figure we have selected tasks with clear latency tendency based on the average (K) value, where

1. $\frac{pr_{ij}^k}{pp_{ij}^k} = 1$ task is realized according to the plan.
2. $\frac{pr_{ij}^k}{pp_{ij}^k} > 1$ task is realized faster than planned.
3. $\frac{pr_{ij}^k}{pp_{ij}^k} < 1$ task is realized slower than planned.

X axis represents the percentage of the task completion. During the first phase (from 0% to 20% of complete tasks durations) all tasks have been realized slower than planned. Then in the next phase (from 20% to 50% of complete task durations) this latency has been gradually reducing. The last phase (above 50% of complete tasks durations) is mainly acceleration for all tasks.

4.3.3. Accuracy of first schedule update

In this section we present how accurate the first updates are during the project realization.

There are five tasks for which the first update created the fuzzy estimation that includes the real task duration within the pessimistic range. In other words for tasks in Table 7 real duration belongs to the range: $[\overline{t}_{ij}, \overline{t}_{ij} + u_{ij}]$

Table 7. Duration time estimation for selected activities at the first stage

Task (i, j)	Stage	$\underline{t}_{ij}$	$\overline{t}_{ij}$	$\underline{t}_{ij} - l_{ij}$	$\overline{t}_{ij} + u_{ij}$	KR_{ij}
(1, 2)	1	2.38	2.38	1.38	3.38	3.25
(2, 3)	1	1.38	1.38	1.38	2.38	2.25
(0, 4)	1	2.38	2.38	1.38	3.38	3.25
(4, 5)	1	1.58	1.58	1.58	2.78	1.25
(0, 6)	1	1.18	1.18	1.18	1.98	1.25

Source: own work.

For two other tasks this pessimistic range contains the real value or the number close to it at the second and third update:

Table 8. Duration time estimation for selected activities at the first and second stage

Task (i, j)	Stage	$\underline{t}_{ij}$	$\overline{t}_{ij}$	$\underline{t}_{ij} - l_{ij}$	$\overline{t}_{ij} + u_{ij}$	KR_{ij}
(0, 1)	2	2.87	2.87	2.87	4.40	4.25
(4, 5)	3	6.01	7.24	4.77	8.48	8.63

Source: own work.

Five other tasks have the appropriate range: $[\underline{t}_{ij}, \overline{t}_{ij}]$ based on the fuzzy estimation that contains the real task duration after the first update.

Table 9. Duration time estimation for selected activities at the first stage

Nr	Stage	$\underline{t}_{ij}$	$\overline{t}_{ij}$	$\underline{t}_{ij} - l_{ij}$	$\overline{t}_{ij} + u_{ij}$	KR_{ij}
(0, 6)	1	3.71	4.54	2.88	5.38	3.88
(0, 8)	1	2.78	3.58	2.78	4.38	2.88
(0, 10)	1	2.57	3.48	2.57	4.39	2.88
(10, 11)	1	3.55	4.48	3.55	5.42	3.88
(0, 12)	1	4.54	5.49	4.54	6.43	5.25

Source: own work.

For 10 over 13 tasks in the project the first update gives the fuzzy estimation that covers the real task durations. A selection of an appropriate PSL^{α} allows a decision maker to align the most appropriate scenario. It emphasizes the significance of the first updates for each task.

5. Conclusions

In this paper we proposed a new approach for selecting the appropriate resource allocation strategy at the project level while turning a fuzzy project schedule (in the planning project phase or during the project execution) into a crisp schedule for the resources at a selected security level. The method is an interactive tool for a decision maker. It requires only that the decision maker selects a security level for the whole project – the security levels for individual activities are automatically calculated by the algorithm.

We also showed the benefits of having fuzzy schedule in addition to the crisp one. First, it allows a better risk control at different α-levels selected by the decision maker. Moreover, the real project used here as an example showed that first fuzzy updates during project execution are of high significance, as for 10 over 13 tasks the fuzzy estimations covered actual activities durations.

One of many benefits of reactive approach is the possibility to measure project progress and react accordingly. Thanks to this approach, for the example project we have identified a big group of tasks with latency tendency over first 20% of their total duration. This kind of observations allow the project manager to make appropriate decisions. The real project used here had a latency tendency. Thus it was better to choose high security level and therefore pessimistic scenario for the whole project.

In the next paper we would like to develop project security level method to make it use the whole shape of fuzzy numbers – not only their projection on the X axis. This may result in more accurate results.

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PROAKTYWNE I REAKTYWNE HARMONOGRAMOWANIE W PRAKTYCE

Streszczenie: W niniejszym artykule zaproponowano rozwinięcie metody proaktywnego i reaktywnego harmonogramowania [Janczura, Kuchta 2011], w której do modelowania niepewności czasów trwania zadań zastosowano liczby rozmyte. W takim przypadku do alokacji zasobów trzeba wykorzystywać deterministyczne reprezentacje liczb rozmytych. W proponowanej metodzie przy wyznaczaniu tych reprezentacji wykorzystano model trzech strategii. Pierwsza z nich bazuje na wartości średniej. Dwie pozostałe polegają na optymistycznej lub pesymistycznej ocenie czasu trwania zadania dokonanej przez eksperta. Zasoby ludzkie są przydzielane w zależności od strategii przyjętej przez kierownika projektu. W niniejszym artykule zaproponowano algorytm wyboru najlepszej strategii odpowiedniej do osiągnięcia najkrótszego terminu zakończenia projektu, odpowiadającej zadanemu przez decydenta po-ziomowi bezpieczeństwa projektu. Dla zilustrowania zaproponowanego podejścia, algorytm został przetestowany na danych dotyczących rzeczywistego projektu.

Słowa kluczowe: zarządzanie projektami, harmonogramowanie proaktywne i reaktywne, liczby rozmyte.