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Fuzzy Logic: An Instrument for the Evaluation of Project Status

Doskočil, Radek
Department of Informatics
Brno University of Technology (Czech Republic)
E-mail: doskocil@fbm.vutbr.cz

ABSTRACT

This article considers the use of fuzzy logic to support the evaluation of project status. A brief description of fuzzy set theory, fuzzy logic and the process of calculation is given. The major goal of this paper is to present an expert decision-making fuzzy model for evaluating project status. The model results from the application of the Fuzzy Logic Toolbox. This fuzzy model is based on two basic indices, schedule performance index (SPI) and cost performance index (CPI), of earned value management (EVM). The advantage of the fuzzy model is the ability to transform the input indices SPI and CPI into linguistic variables, as well as linguistic evaluation of overall project status (output). With this approach it is possible to simulate the risk and uncertainty that are always associated with real projects. The scheme of the model, rule block, attributes and their membership functions are mentioned in a case study. The case study contains real data on the development of values of indices SPI and CPI for one project in the field of IT (data file). The analysed project ran from March 2012 to July 2012. The indices SPI and CPI were obtained from control project milestones. There are 5 control milestones in total. The parameters of the model are adjusted on the basis of the data file for each of the variables. The use of fuzzy logic is a particular advantage in decision-making processes where description by algorithms is extremely difficult and criteria are multiplied.

Keywords: project management; earned value management (EVM); soft computing; fuzzy logic; decision-making.
JEL classification: C44; M19; M21.
MSC2010: 90C70.

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La lógica difusa: un instrumento para la evaluación del estado del proyecto

RESUMEN

El artículo trata sobre el uso de la lógica difusa como soporte para la evaluación del estado de un proyecto. Se describe brevemente la teoría de conjuntos difusos, la lógica difusa y el proceso de cálculo. El objetivo principal de este trabajo es presentar un modelo difuso para la toma de decisiones por parte de expertos para la evaluación del estado de un proyecto. El modelo es resultado de aplicar la librería de lógica difusa de MATLAB. Este modelo difuso se basa en dos índices básicos, el índice de desempeño de programación (IDP) y el índice de desempeño de costos (IDC), de la gestión del valor ganado (GVG). La ventaja del modelo difuso reside en su capacidad de traducir los índices de entrada IDP e IDC en variables lingüísticas, así como en proporcionar una evaluación lingüística del estado general del proyecto (output). Con este enfoque es posible simular el riesgo y la incertidumbre que siempre está asociado con los proyectos reales. El esquema del modelo, su bloque de reglas, sus atributos y sus funciones de pertenencia, son mencionados en un estudio de caso, el cual contiene datos reales sobre el desarrollo de los valores de los índices IDP e IDC para un proyecto en el ámbito de las TI (archivo de datos). El proyecto analizado duró desde marzo de 2012 hasta julio de 2012. Los índices IDP e IDC se obtuvieron de los hitos del proyecto de control. En total, hay 5 hitos de control. Los parámetros del modelo se ajustan basándose en el archivo de datos para cada una de las variables. El uso de la lógica difusa es una ventaja, especialmente en los procesos de toma de decisiones ya que, en éstos, resulta muy difícil una descripción mediante algoritmos y se multiplican los criterios.

Palabras clave: gestión de proyectos; gestión del valor ganado (GVG); soft computing; lógica difusa; toma de decisiones.
Clasificación JEL: C44; M19; M21.
MSC2010: 90C70.

1. INTRODUCTION

Project management is a widely discussed discipline at the present time. This fact is substantiated by numerous scientific articles, books and publications dealing with these problems (Bergantiños, Vidal-Puga, 2009; Pérez, Rambaud, García, 2005; Rosenau, 2007; Smejkal, Rais, 2013; Schwable, 2011; Doležal, Máchal, Lacko, 2009). This discipline is also included in the courses of numerous faculties focusing on economics both in the Czech Republic and abroad. Experts are also affiliated in various professional organisations and associations (Společnost pro projektové řízení Česká republika, 2011; International Project Management Association, 2011).

Project managers and other members of the project team use different tools, techniques and methods in project management. Earned Value Management (EVM) is an extremely important technique in project management. It is used to measure project progress and to assess its effectiveness. The EVM technique is also supported by software for supporting project management (e.g. MS Project, Primavera) today. For more detailed information about the EVM technique see related publications (Project Management Institute, 2013; Lacko, Šviráková, 2013).

The major goal of this paper is to present a new expert decision-making fuzzy model for evaluating project status. This fuzzy model is based on the earned value methodology. The advantage of the fuzzy model is the ability to transform the input indices SPI and CPI into linguistic variables, as well as linguistic evaluated overall project status (output). Using this approach it is possible to simulate the risk and the uncertainty that are always associated with projects.

The application of fuzzy logic (Dostál, 2008; Doskočil, Kříž, Koch, 2009) is based on the fuzzy set theory (Zadeh, 1965; Zimmermann, 1991; Klir, Yuan, 1995). Many authors have also focused on the theory of fuzzy sets and applications of fuzzy logic in project management (Relich, Muszyński, 2014). The EVM technique is also a scientific goal for some authors (Naeni, Shadrokh, Salehipour, 2011; Lipke, Zwikael, Henderson, Anbari, 2009; Khamooshi, Golafshani, 2014; Noori, Bagherpour, Zareei, 2008). In his article, the author Rowe presents the basic facts about what EVM was in the past, what it is today, and what has been done for a better understanding of its current practice across various industrial sectors and geographic regions. A search of the literature has revealed that EVM has been recognised for its value to project management in both the defence industry and private industry in the USA and a number of other countries for more than forty years. EVM has been accepted as a best practice for performance management (Rowe, 2010). The article by the authors Chuo, Chen, Hou and Lin presents a web-based visualised architecture, design and implementation for assessing IT project performance by integrating EVM and a database management system (DBMS). The management information system (MIS) developed provides an objective measure of completed work that can be used to monitor project progress (Chuo, Chen, Hou, Lin, 2010). The research by the authors Siu and Lu proposes a refined approach based on discrete event simulation (scheduling simulation) to tackle complicated resource-constrained scheduling. A case study is used to demonstrate its applications on a resource-constrained schedule under postulated delay scenarios. It is shown that this approach is conducive to truthfully reflecting the project performance status given a resource-constrained schedule subject to complicated activity-project delay (Siu, Lu, 2011). The authors Acabes, Pajares, Galán and López-Paredes present a new methodology for project control under uncertainty in their article "A new approach for project control under uncertainty. Going back to the basics". This methodology integrates EVM with project risk analysis. The steps taken to implement the methodology are shown in three case studies (Acabes, Pajares, Galán, López-Paredes, 2014). The author Czemplik proposes application of the method together with complementary – dedicated for EVM – known approaches, making the method well adjusted for use on dynamic and multidisciplinary construction projects (Czemplik, 2014). The authors Chou and Chong present how to lay out a visualised architecture of project performance measurement that integrates earned value analysis and control within a web-based system that would allow construction personnel to track, modify and update cost and time-based data of project status on-line (Chou, Chong, 2008). The authors Moslemi Naeni and Salehipour present an approach for dealing with fuzzy earned value indices including developing new indices under fuzzy circumstances and evaluating them using the alpha cut method. The proposed model (illustrated in the case study) improves the applicability of the earned value techniques under real-life and uncertain conditions (Moslemi Naeni, Salehipour, 2011). The authors Kuchta, Chanas and Zielinski, Oliveros and Fayek, Bushan and Shankar, Doskočil and Doubravský have presented fuzzy sets using fuzzy numbers to obtain critical project paths (Kuchta, 2001; Chanas and Zielinski, 2001; Oliveros, Fayek, 2005; Bushan and Shankar, 2012; Doskočil, Doubravský, 2013).

2. THEORETICAL BACKGROUND

2.1. Earned Value Management (EVM)

The EVM method is based on the following indices:

- Planned value (PV) – budgeted cost of work scheduled (BCWS)
  The total PV of a task = the task's budget at completion (BAC)
- Earned value (EV) – budgeted cost of work performed (BCWP)
- Actual cost (AC) – actual cost of work performed (ACWP)

EVM uses the following basic indices for describing project schedule and cost performance:

- Schedule variance (SV) – shows whether and by how much your work is ahead of or behind your approved schedule. Mathematically: SV = EV – PV
- Cost variance (CV) – shows whether and by how much you are under or over your approved budget. Mathematically: SV = EV – AC
- Schedule performance index (SPI) – shows the relative amount the project is ahead of or behind schedule. Mathematically: SPI = EV / PV. Interpretation:
  SPI < 1: the project is behind schedule (finish later than expected)
  SPI > 1: the project is ahead of schedule (finish sooner than expected)
  SPI = 1: the project is on schedule (finish according to schedule)
- Cost performance index (CPI) – shows the relative value of work done compared to the amount paid for it. Mathematically: CPI = EV / AC. Interpretation:
  CPI < 1: the project is over budget
  CPI > 1: the project is under budget
  CPI > 1: the project is within budget

A graphical representation of PV, EV, AC, BAC, SV and CV is given in Fig. 1.

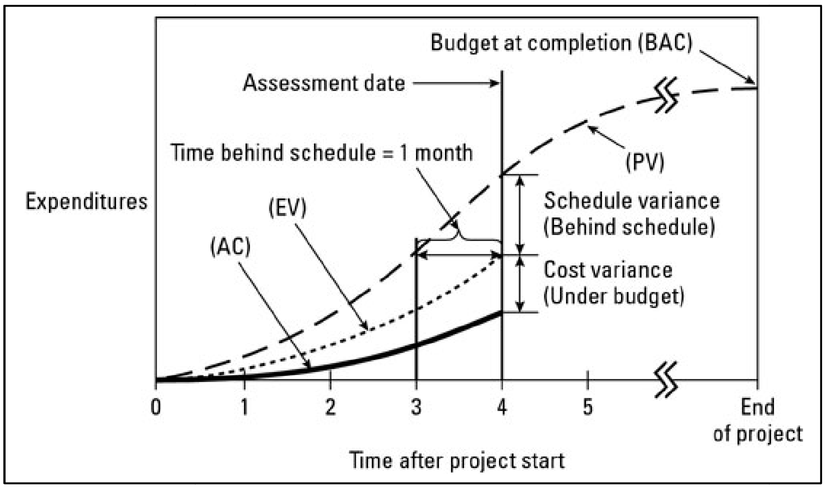

Fig. 1: Graphical representation of basic EVM indices (Source: Earned Value Management Terms and Formulas for Project Managers, 2014)

2.2 Fuzzy modelling

2.2.1 Fuzzy set theory

A fuzzy set is a set whose elements have degrees of membership. The fuzzy set was introduced by Lotfi A. Zadeh in 1965 as an extension of the classical notion of sets and can be applied in many fields of human activity. The degree of membership to fuzzy sets determines "how much" the element belongs to the set. This is the basic principle of fuzzy sets.

A fuzzy set can be defined as follows: Let X be a non-empty set and $\mu_{\tilde{A}}: X \to [0;1]$. Then fuzzy set $\tilde{A}$ is a set of all ordered pairs $(x, \mu_A(x))$ therefore

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)): x \in X, \mu_{\tilde{A}}(x) \in [0;1]\}. \quad (1)$$

where X is a universe of discourse, $\mu_{\tilde{A}}$ is a membership function of fuzzy set $\tilde{A}$ (see Fig. 2 for two examples of the shape of membership functions) and $\mu_{\tilde{A}}(x)$ is a grade of membership of x. $\mu_{\tilde{A}}$ is defined for all $x \in X$ and $\mu_{\tilde{A}}(x) = 0$ for $x \notin \tilde{A}$.

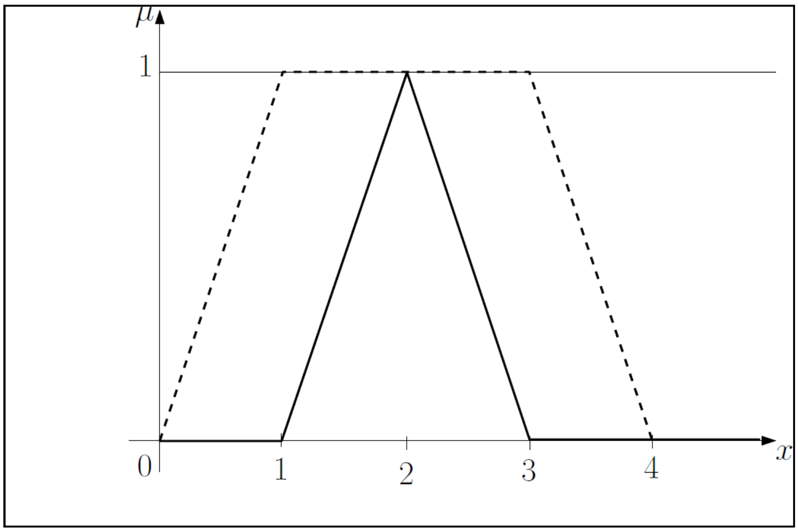

Fig. 2: Triangular and trapezoidal type of membership function

A fuzzy set $\tilde{A} = (\boldsymbol{R}, \mu_{\tilde{A}})$ is called a real fuzzy number on a set of real numbers $\boldsymbol{R}$ when it fulfils the following conditions:

- Fuzzy set $\tilde{A}$ is convex ($\mu_{\tilde{A}}$ is a convex function)
- Fuzzy set $\tilde{A}$ is normal (hgt $\tilde{A} = 1$)
- $\mu_{\tilde{A}}$ is a piecewise continuous function

Let α be a number form $[0;1]$ then α level cut of fuzzy set $\tilde{A}$ is a classical set

$$A_\alpha = \{x \in X: \mu_{\tilde{A}}(x) \geq \alpha\}. \quad (2)$$

Basic binary operations are used with fuzzy numbers, e.g. $+,-,\times,/$. Let $*$ be a binary operation on $\boldsymbol{R}$ then an extended binary operation on $\mathcal{A}$, where $\mathcal{A}$ is a set of all fuzzy numbers, means an operation $\circledast$, e.g. $\oplus$, $\ominus$, $\otimes$, $\oslash$.

$$\mu_{\tilde{A}\circledast\tilde{B}}(z) = \sup_{\substack{x,y \\ x*y=z}} \min\{\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(y)\}. \tag{3}$$

Practical computing of the extended binary operations is often realised by α level cut (2). For increasing binary operation the extended binary operations are

$$\tilde{A} \circledast \tilde{B} = \bigcup_{\alpha\in[0;1]} \alpha\ A_{\alpha} \circledast B_{\alpha}. \tag{4}$$

If we denote $A_{\alpha} = [a_{1\alpha}; a_{2\alpha}]$ and $B_{\alpha} = [b_{1\alpha}; b_{2\alpha}]$ then the extended binary operation for increasing binary operation $*$ is

$$A_{\alpha} \circledast B_{\alpha} = [a_{1\alpha}; a_{2\alpha}] \circledast [b_{1\alpha}; b_{2\alpha}]. \tag{5}$$

Each α level cut of a fuzzy number can be regarded as the interval number. The interval number means interval $[a; b]$ where $a \leq b$, a and b are real numbers (Karpíšek, 2009).

Arithmetic operations on interval numbers are defined following relationships (Dostál, 2008):

$[a; b] + [c; d] = [a + c; b + d]$

$[a; b] - [c; d] = [a - d; b - c]$

$[a; b] \cdot [c; d] = [\min\{ac, ad, bc, bd\}; max\,\{ac, ad, bc, bd\}]$

$[a; b]\ /\ [c; d] = [\min\{a / c, a / d, b / c, b / d\}; max\,\{a / c, a / d, b / c, b / d\}]$

2.2.2 Fuzzy logic

Fuzzy logic measures the certainty or uncertainty of how much the element belongs to the set. By means of fuzzy logic, it is possible to find the solution of a given task from rules, defined for analogous tasks. The calculation of fuzzy logics consists of three basic steps: see Fig 3.

1. Fuzzification – transforms real variables into linguistic variables using their attributes. The variable usually has from three to seven attributes. The attribute and membership functions are defined for input and output variables. The degree of membership of attributes is expressed by a mathematical function – membership function (Π, Z, S, etc.) (Dostál, 2008).

2. Fuzzy inference – defines the behaviour of a system by using rules of type <When>, <Then> on a linguistic level. Conditional clauses typically have the following form:
   <When> [Input_a1 <And> Input_a2 <And> ... <And> Input_an] < And > [Input_b1 <And> Input_b2 <And> ... <And> Input_bm] <Then> Output_1.
   Each combination of attributes of input and output variables, occurring in condition <When>, <Then>, presents one rule. The rules are created by the user or expert himself (Dostál, 2008).
3. Defuzzification – transfers the results of fuzzy inference (numerical values) on output variables by linguistic values. It describes results verbally (Dostál, 2008).

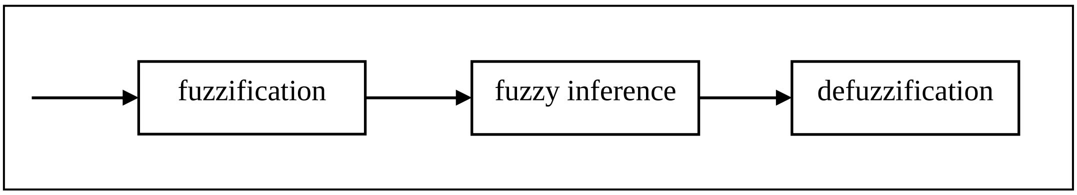

Fig. 3: Decision-making – solved by fuzzy processing (Source: Dostál, 2008)

A system with fuzzy logic works as an automatic system. The user must enter input data only. These can be represented by many variables and their attributes.

4. METHODOLOGY RESEARCH

The case study presents the use of fuzzy logic in the evaluation of project status on base on the basis of Earned Value management (EVM).

The analysed project is in the field of IT. The project ran from March 2012 to July 2012. The aim of the IT project is to design an application that allows to optimize the communication between the other two applications. The indices SPI and CPI were obtained from a checkpoints project. In total there are 5 checkpoints projects (control milestones), i.e. data file was formed based on indices SPI and CPI. See Table. 1.

Table 1: Data file

Checkpoints project	SPI	CPI
End of March 2012	0.89	0.94
End of April 2012	0.97	1.18
End of May 2012	0.93	1.15
End of June 2012	0.89	1.10
End of July 2012	1.00	1.05

Source: Mertl, J., 2014

The practical application of EVM is usually defined by certain tolerances which are represented in a graphic circle centred in point (1,1). These circles are the relevant size of the problem in which the project is located – problem of project status (PS). The closer to the centre (point (1,1)), the smaller the problems of project status are. The further away from the centre (point (1,1)) the greater the problems of project status. See Fig. 4.

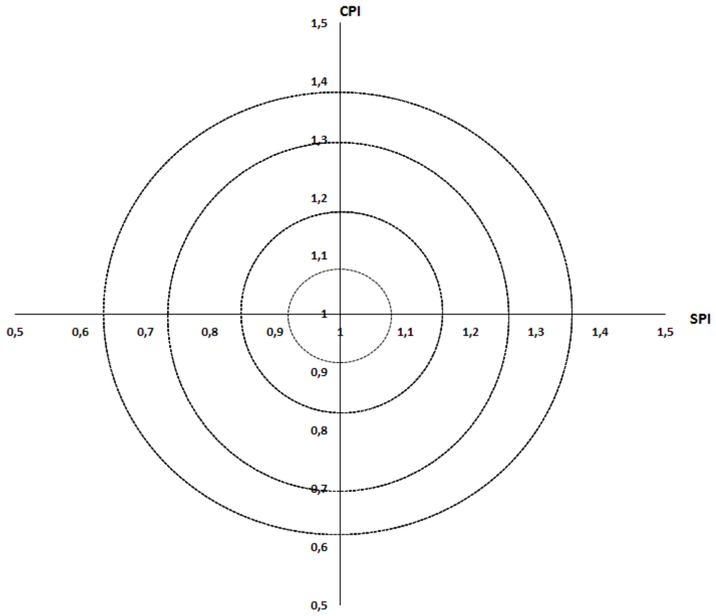

Fig. 4: Status chart SPI, CPI (Source: own research)

Deviations from the centre (point (1,1)) were calculated from the input data. See columns 2 and 3 of Table 2. Five attributes has been set for output variable – problem of project status (PS):

VS – very small (deviations from the (point [(1,1)) within 5%, i.e. interval $[0{,}95; 1{,}05]$

S – small (deviations from the (point (1,1)) within 10%, i.e. interval $[0{,}90; 1{,}00]$

M – medium (deviations from the (point (1,1)) within 15%, i.e. interval $[0{,}85; 1{,}15]$

L – large (deviations from the (point (1,1)) within 20%, i.e. interval $[0{,}80; 1{,}20]$

VL – very large (deviations from the (point (1,1)) more than 20%. i.e. above 0,80 and 1,20.

For each interval is calculated deviation from point (1,1): 0; 0,05; 0,10; 0,15; 0,20;0,25. From these values are defined following new intervals: $[0; 0{,}05)$, $[0{,}05; 0{,}10)$, $[0{,}10; 0{,}15)$, $[0{,}15; 0{,}20)$, $[0{,}20; 0{,}25)$. The centre of each intervals represents numeric representative of attributes of output variable PS. Attribute VS = 0,02, S = 0,07, M = 0,12, L = 0,17, VL = 0,22. See column 4 of Table 2. Columns 5, 6 and 7 in Table 2 present normalised data of SPI, CPI and PS into the range $[0; 100]$. This range is used in the creation of the fuzzy model.

Table 2: Data file – modified for fuzzy model

Checkpoints project	SPI_deviation from the point (1,1)	CPI_deviation from the point (1,1)	PS_deviation from the point (1,1)	SPI_normalised to the range [0; 100]	CPI_normalised to the range [0; 100]	PS_normalised to the range [0; 100]
End of March 2012	0.11	0.06	0.12	45.83	25.00	54.55
End of April 2012	0.03	0.18	0.12	12.50	75.00	54.55
End of May 2012	0.07	0.15	0.12	29.17	62.50	54.55
End of June 2012	0.11	0.10	0.12	45.83	41.67	54.55
End of July 2012	0.00	0.05	0.02	0.00	20.83	9.09

(Source: own research)

The Fuzzy Logic Toolbox in MATLAB software was used to create the decision-making model. The developed expert decision-making fuzzy model system (EDMS_PS) consists of two input variables, one rule box and one output variable. The inputs are represented by two variables: SPI_deviation (SPI) and CPI_deviation (CPI). The output from the rule box and the output variable is PS_deviation (PS). See Fig. 5.

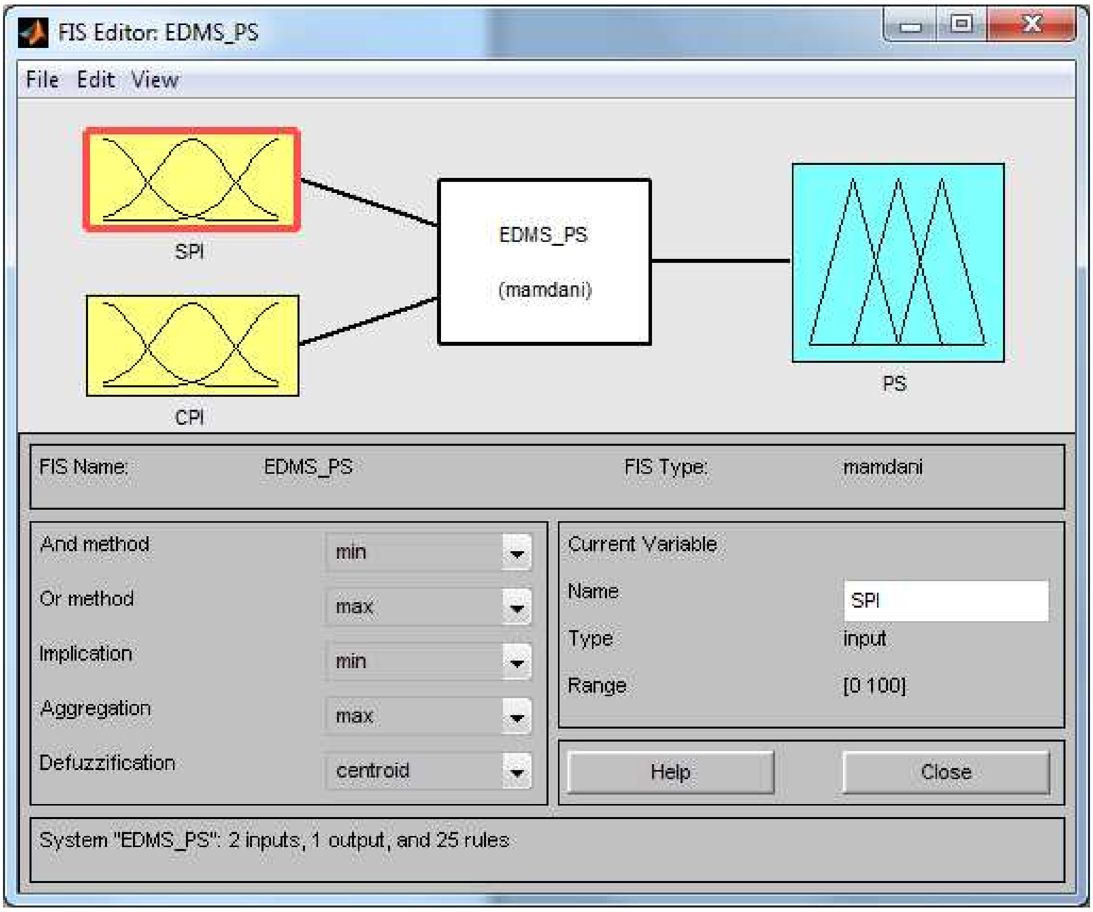

Fig. 5: Build up model (Source: own research)

The input variable SPI has five attributes: VS – very small, S – small, M – medium, L – large, VL – very large. A membership function of type Π (*trapmf)* was used. The input variable CPI has five attributes: VS – very small, S – small, M – medium, L – large, VL – very large. A membership function of type Π (*trapmf)* was used. The output variable PS has with five attributes: VS – very small, S – small, M – medium, L – large, VL – very large. A membership function of type Π (*trapmf)* was used. See Fig. 6.

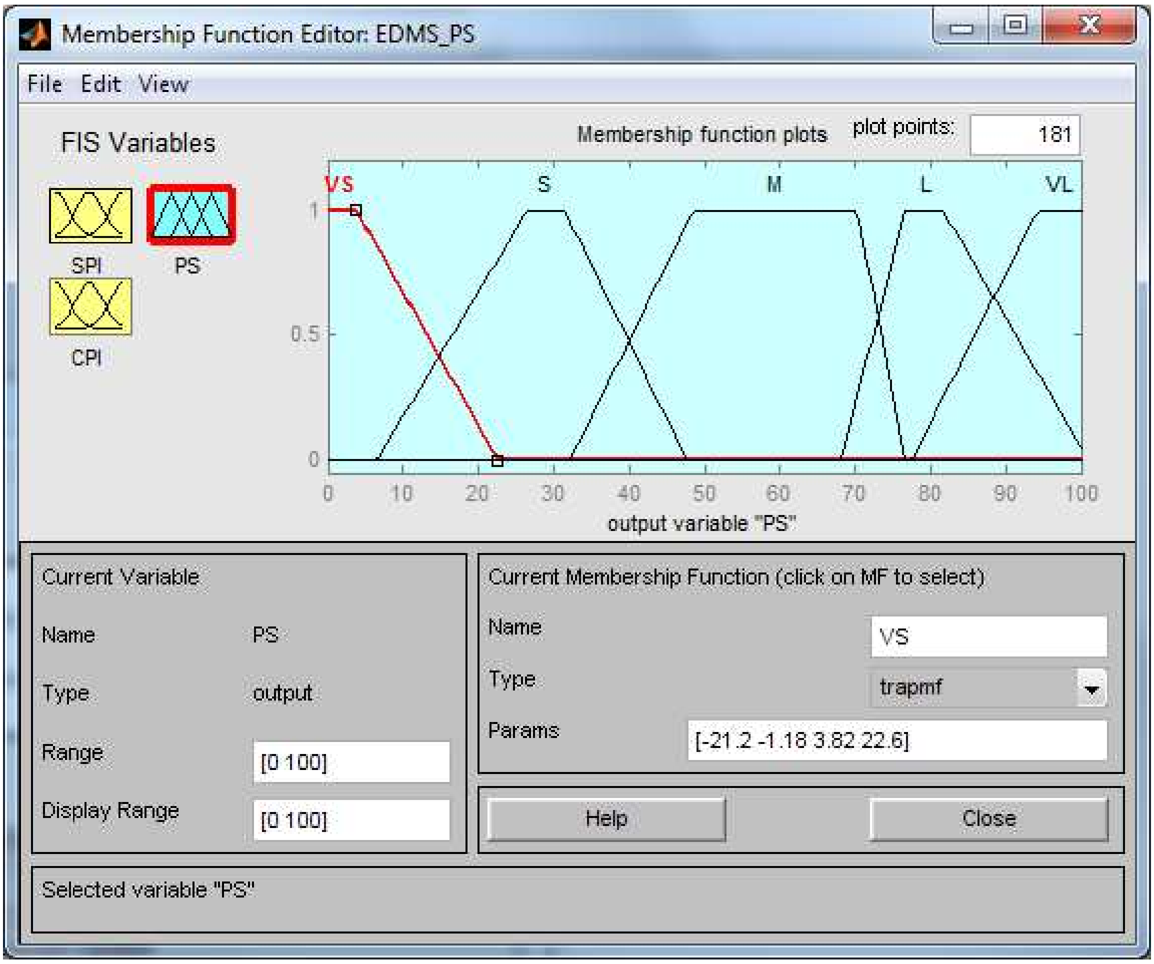

Fig. 6: The attributes and membership functions of output variable (PS)
(Source: own research)

The parameters of membership functions are adjusted on the basis of the data file (see Table 2) for each of the variables (see Fig. 7).

```
[Input1]
Name='SPI'
Range=[0 100]
NumMFs=5
MF1='VS':'trapmf',[-22.5 -2.5 8.33 22.5]
MF2='S':'trapmf',[-1.73 18.3 29 43.3]
MF3='M':'trapmf',[30.4 47.2 63.6 63.6]
MF4='L':'trapmf',[52.5 72.5 77.5 97.5]
MF5='VL':'trapmf',[77.5 90.9 103 123]

[Input2]
Name='CPI'
Range=[0 100]
NumMFs=5
MF1='VS':'trapmf',[-17.473544973545 2.52645502645503 7.52645502645503 27.526455026455]
MF2='S':'trapmf',[-0.145502645502646 19.8544973544974 24.8544973544974 44.8544973544974]
MF3='M':'trapmf',[27.7 45 58.6 67.063492063492]
MF4='L':'trapmf',[52.5 72.5 77.5 97.5]
MF5='VL':'trapmf',[77.5 88.2 103 123]

[Output1]
Name='PS'
Range=[0 100]
NumMFs=5
MF1='VS':'trapmf',[-21.2 -1.18 3.82 22.6]
MF2='S':'trapmf',[6.47544973544973 26.5354497354497 31.4354497354497 47.7354497354497]
MF3='M':'trapmf',[32.1428571428571 48.6 70.3 76.6]
MF4='L':'trapmf',[68.1 76.7 81.7 101]
MF5='VL':'trapmf',[77.5 94.3121693121693 103 123]
```

Fig. 7: Parameters of membership functions (input 1, input 2, output 1)
(Source: own research)

Fig. 8 shows the rule box with 25 rules and degree of support that set up the relationship between the input and output variables.

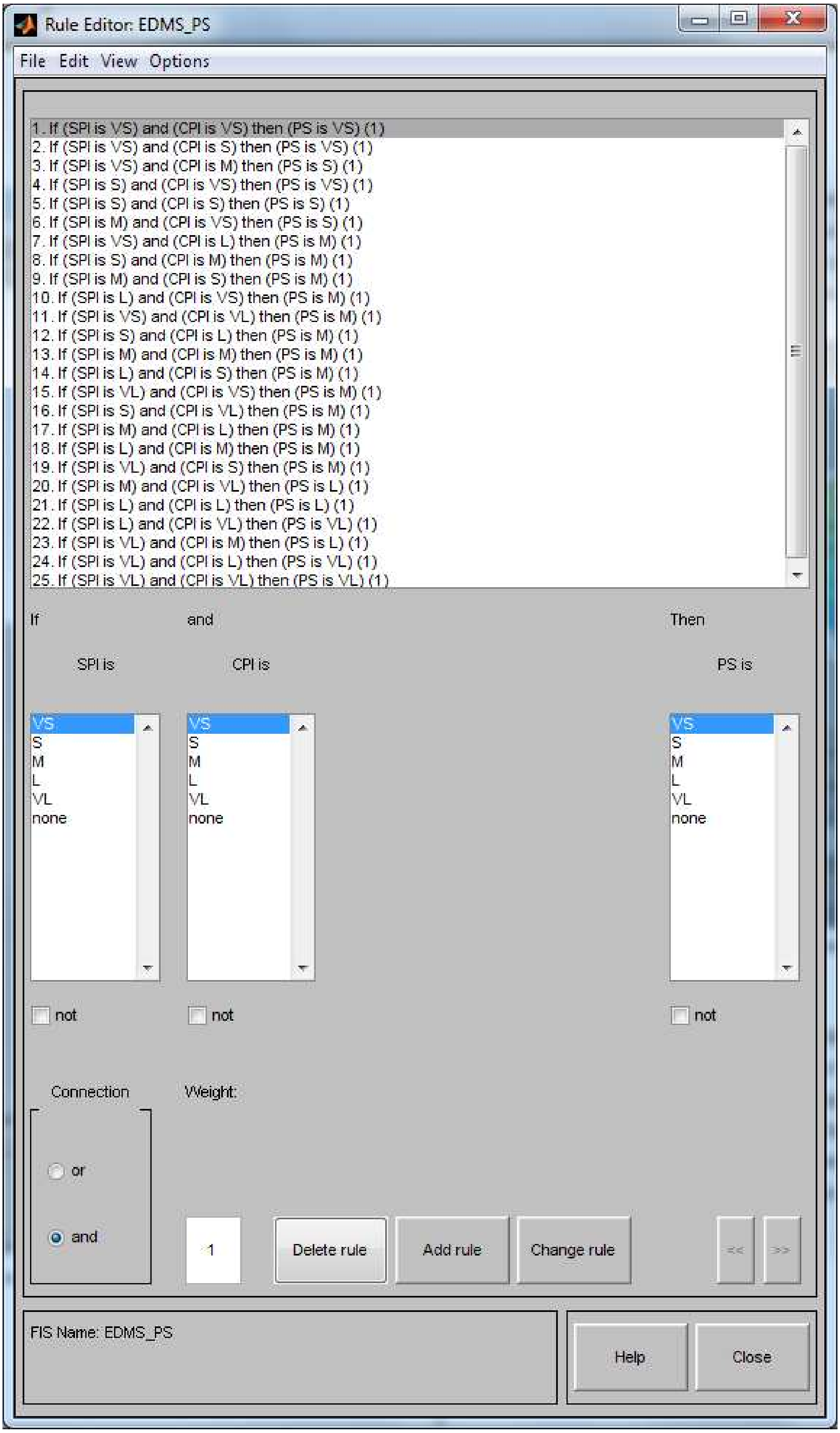

Fig. 8: Rule box and rules (Source: own research)

Fig. 9 shows the correlation between inputs and output. Specifically, this image shows graphically the correlation between two input variables SPI and CPI and output variable PS. The user can change this variable for presentation in graphs. In this graph, you can see extremely important information about the fuzzy model.

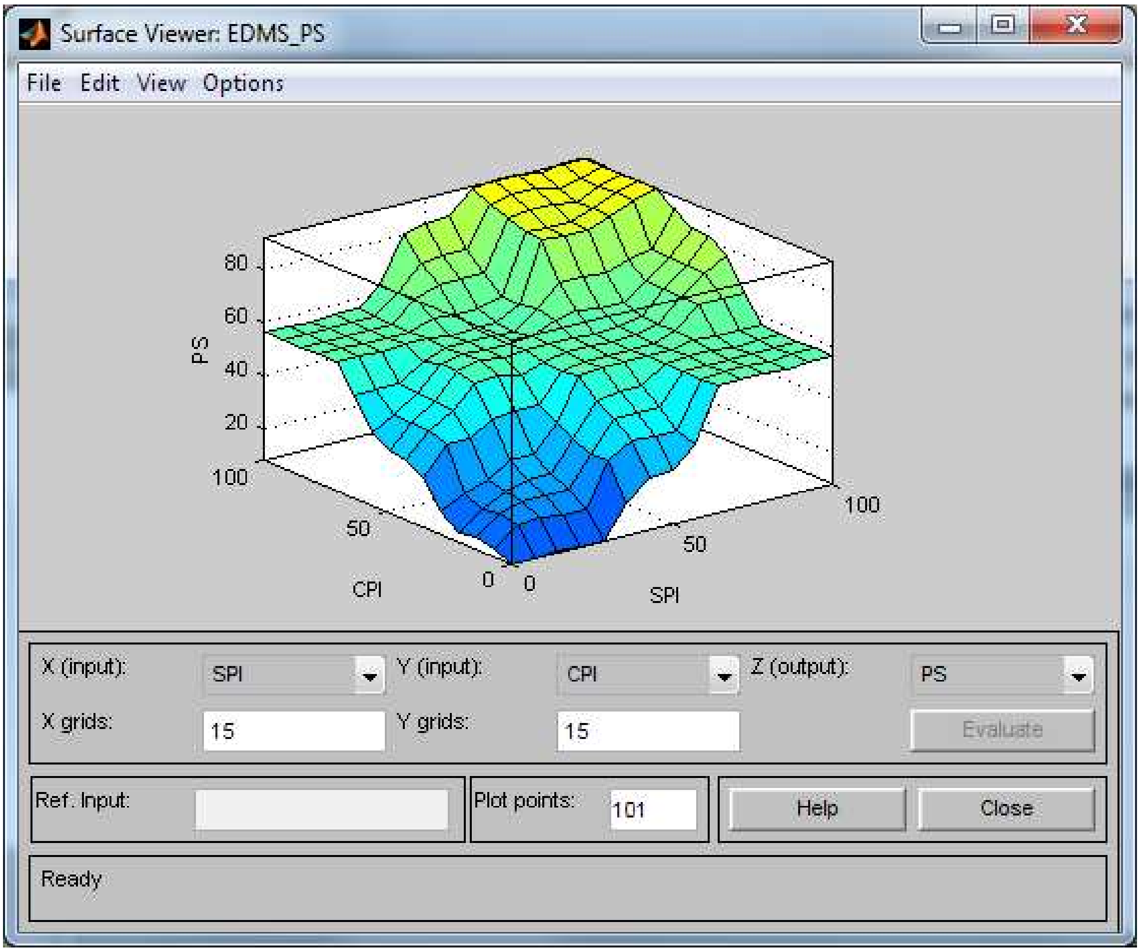

Fig. 9: Correlation between variables (Source: own research)

5. RESULTS AND DISCUSSION

After the model is created, it must be tuned (to set up the inputs on known values, evaluate the results and change the rules or weights, if necessary). The system can be used in practice after it has been tuned. The validation of the fuzzy model was tested on real data (see data file). Fig. 10 shows the evaluation of project status (PS) in one of the checkpoints where the inputs are set up (SPI = 29.2, CPI = 62.5). It leads to the result PS = 55,7 which means that the problem of project status is middle.

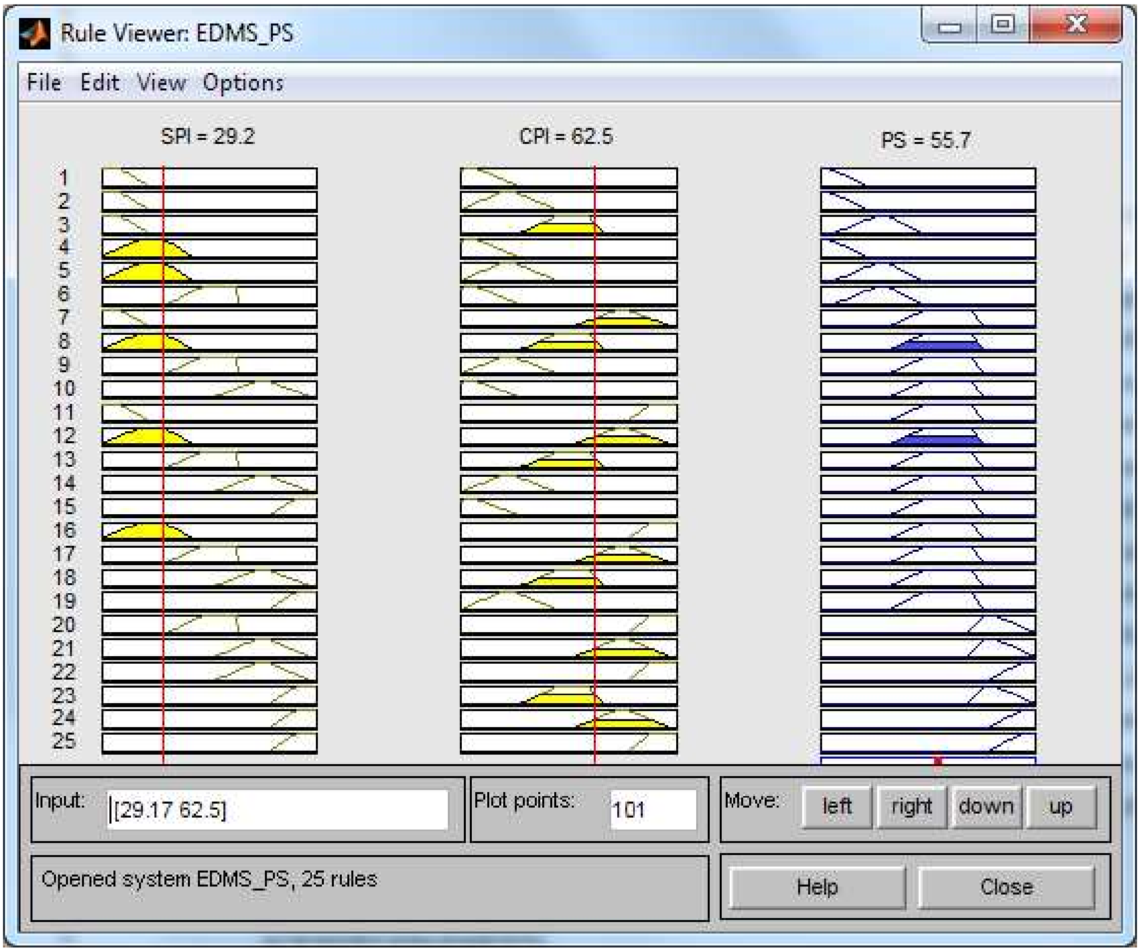

Fig. 10: Validation of the fuzzy model (Source: own research)

The model was tested on the remaining real data in the same way (see data file). The results of the validation show that the model provides relatively accurate results. See Table 3.

Table 3: Validation of the fuzzy model

Checkpoints project	SPI	CPI	PS – real	PS – model
End of March 2012	45.83	25.00	54.55	53.10
End of April 2012	12.50	75.00	54.55	56.10
End of May 2012	29.17	62.50	54.55	55.70
End of June 2012	45.83	41.67	54.55	56.20
End of July 2012	0.00	20.83	9.09	11.10

(Source: own research)

6. CONCLUSIONS

The expert fuzzy decision-making model of project status evaluation is only one of the possible ways of using fuzzy logic to support decision-making. This paper presents a new expert decision-making fuzzy model based on earned value management (EVM). The advantage of the fuzzy model is the ability to transform the input indices SPI and CPI into linguistic variables, as well as linguistic evaluated overall project status (output). With this approach it is possible to simulate the risk and uncertainty that are always associated with projects. The case study contains real data on the values of the indices SPI and CPI, including project status information, and also on the development of the above-mentioned values for one project in the field of IT (data file). The analysed project ran from March 2012 to July 2012. The indices SPI and CPI were obtained from control project milestones. There are 5 control milestones in total. The parameters of the model are adjusted based on the data file for each of the variables. An executable file called M-file can also be created to implement the fuzzy model in MATLAB. M-file is used to enter the input values and automatically evaluate the status of the project. The fuzzy model has many benefits for users (project managers and others), including automation and standardisation of the decision-making process, speeding up the decision-making process, effective project management, simulation of possible development project, etc.

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