JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Fuzzy logic: An instrument for the evaluation of Project Risk Analysis and status

Akash Soni
Research Scholar
Kalinga University, New Raipur (C.G.)

Dr. C. Ramesh Kumar
Co- Supervisor
Department of Mathematics
Rungta College of Engg. & Technology,
Bhilai (C.G.)

Dr. Rahul Dwivedi
Supervisor
Department of Mathematics
Kalinga University, New Raipur (C.G.)

ABSTRACT

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. 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.

Keywords : EVM, Fuzzy Logic, Fuzzy Modeling, SPI, CPI.

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).

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 visualise.

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

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

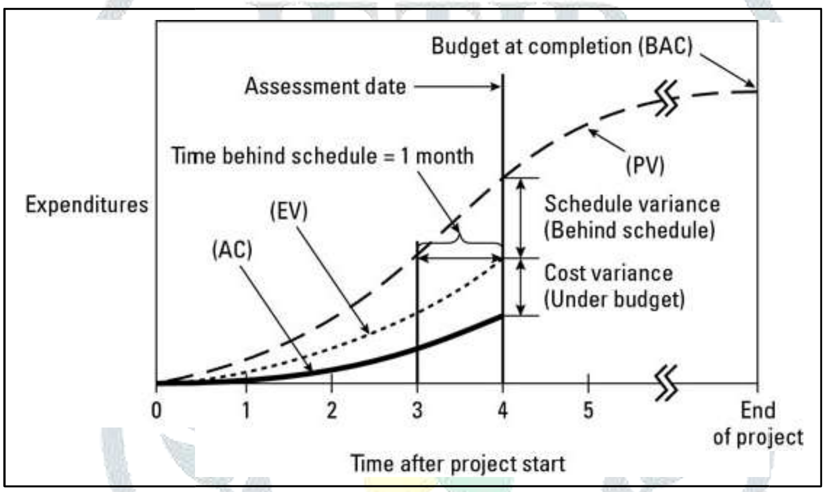


Fig. 1: Graphical representation of basic EVM indices (Source: Earned Value Management Terms and Formulas for Project Managers, 2014)

Fuzzy modelling

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 $\mu_{\tilde{A}}: X \rightarrow [0; 1]$.

Then fuzzy set $\tilde{A}$ is a set of all ordered pairs $(x, \mu_{\tilde{A}}(x))$ 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 $x \notin \tilde{A}$.

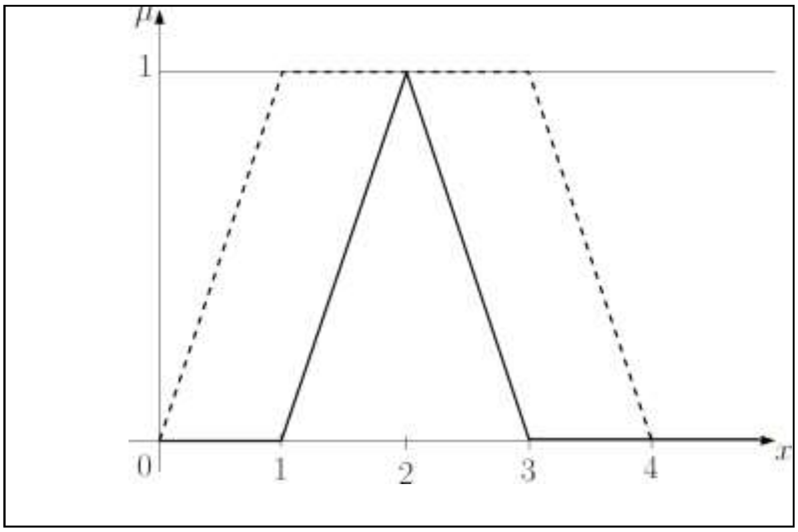


Fig. 2: Triangular and trapezoidal type of membership function

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

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

$$A_\alpha = \{x \in X : \mu_{Æ}(x) \geq \alpha\}. \qquad (2)$$

Basic binary operations are used with fuzzy numbers, e.g. +, −, ×, ⁄. Let ∗ be a binary operation on R then an extended binary operation on Æ, where Æ is a set of all fuzzy numbers, means an operation ⊛ e.g. ⊕, ⊖, ⊗, ⊘.

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

,

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

$$\tilde{A} \odot \tilde{B} = \bigcup_{\alpha \in [0,1]} \alpha \, A_\alpha \odot B_\alpha. \qquad (4)$$

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

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

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

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

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

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

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

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

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).

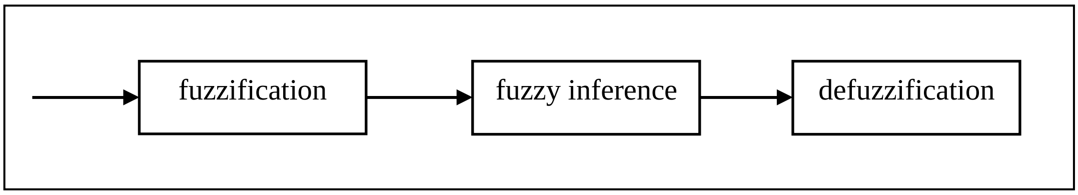


Fig. 3: Decision-making – solved by fuzzy processing (Source: Dostál, 2008)

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 2019 to July 2020. 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 2019	0.89	0.94
End of April 2019	0.97	1.18
End of May 2019	0.93	1.15
End of June 2020	0.89	1.10
End of July 2020	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 r levant 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.

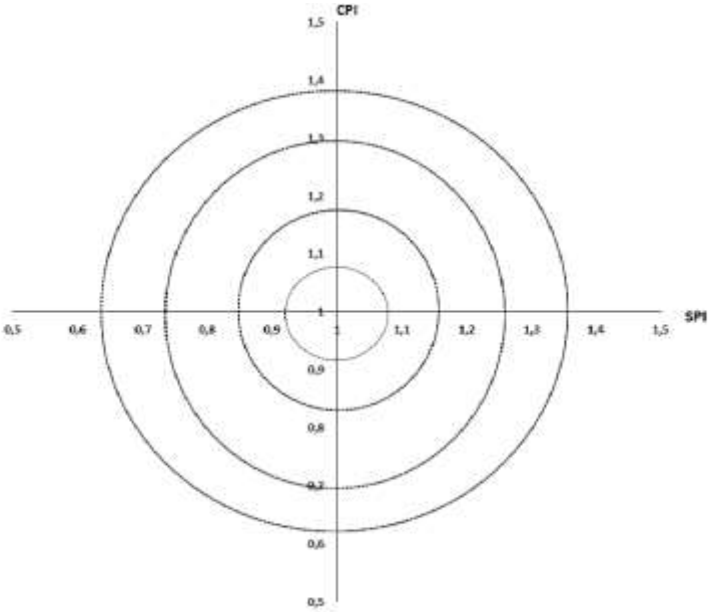


Fig. 4: Status chart SPI, CPI (Source: own research)

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 normalise data of SPI, CPI and PS into the range [0; 100]. This range is used in the creation of the fuzzy model.

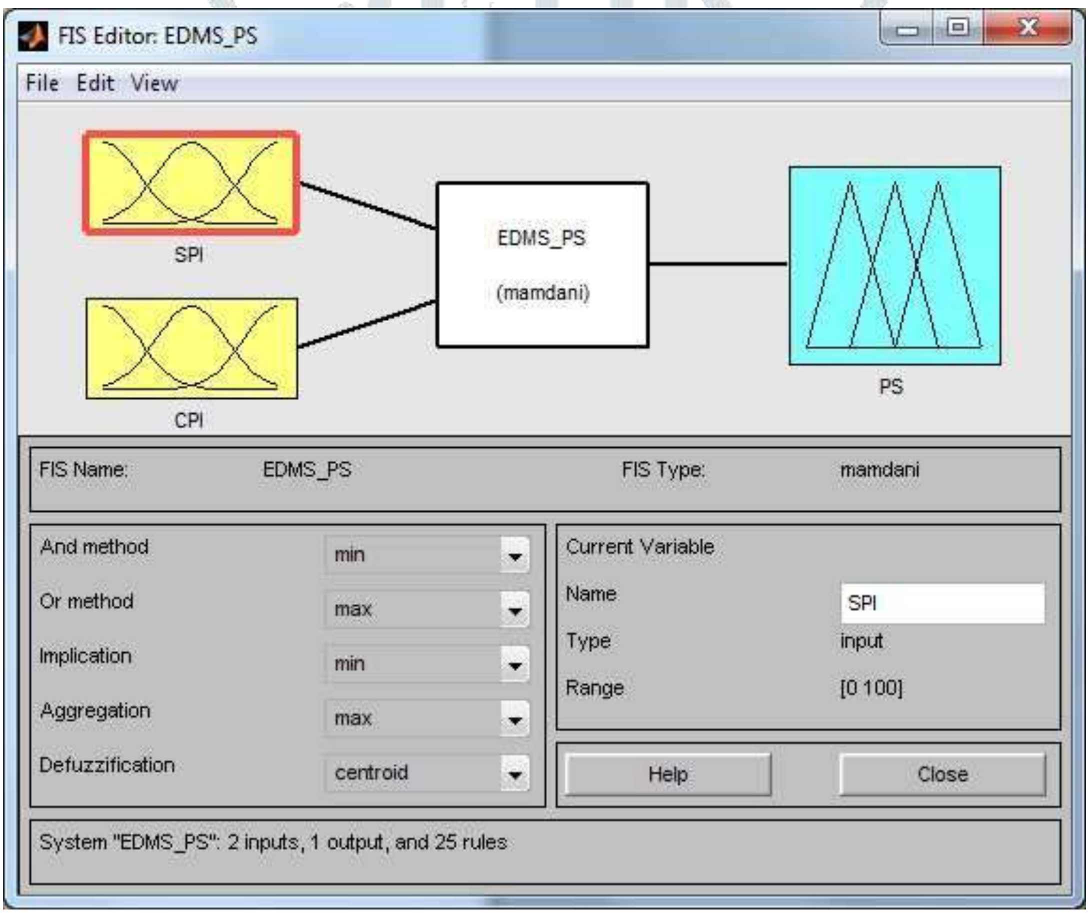
Table 2: Data file – modified for fuzzy model

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.

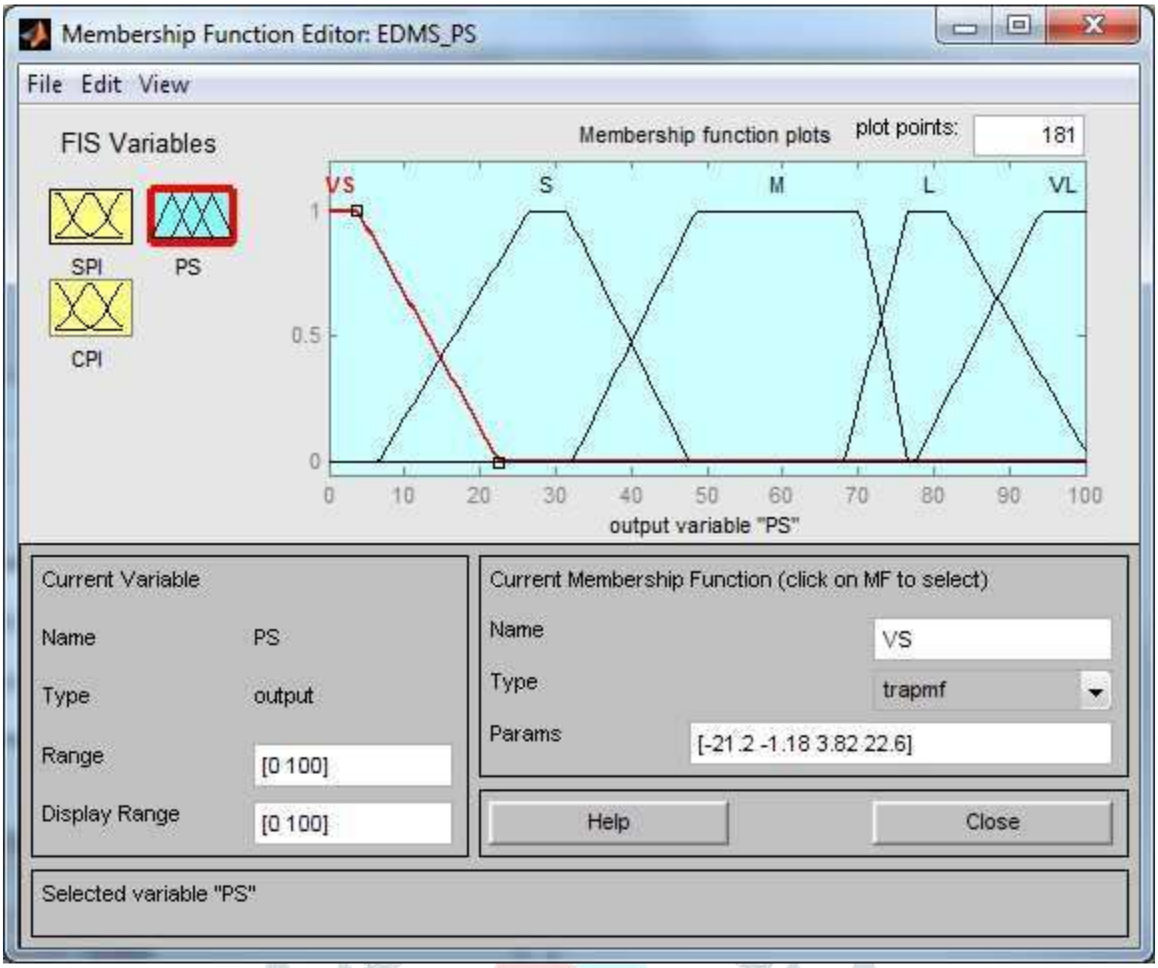


Fig. 6: The attributes and membership functions of output variable (PS) (Source: own research)

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).

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.

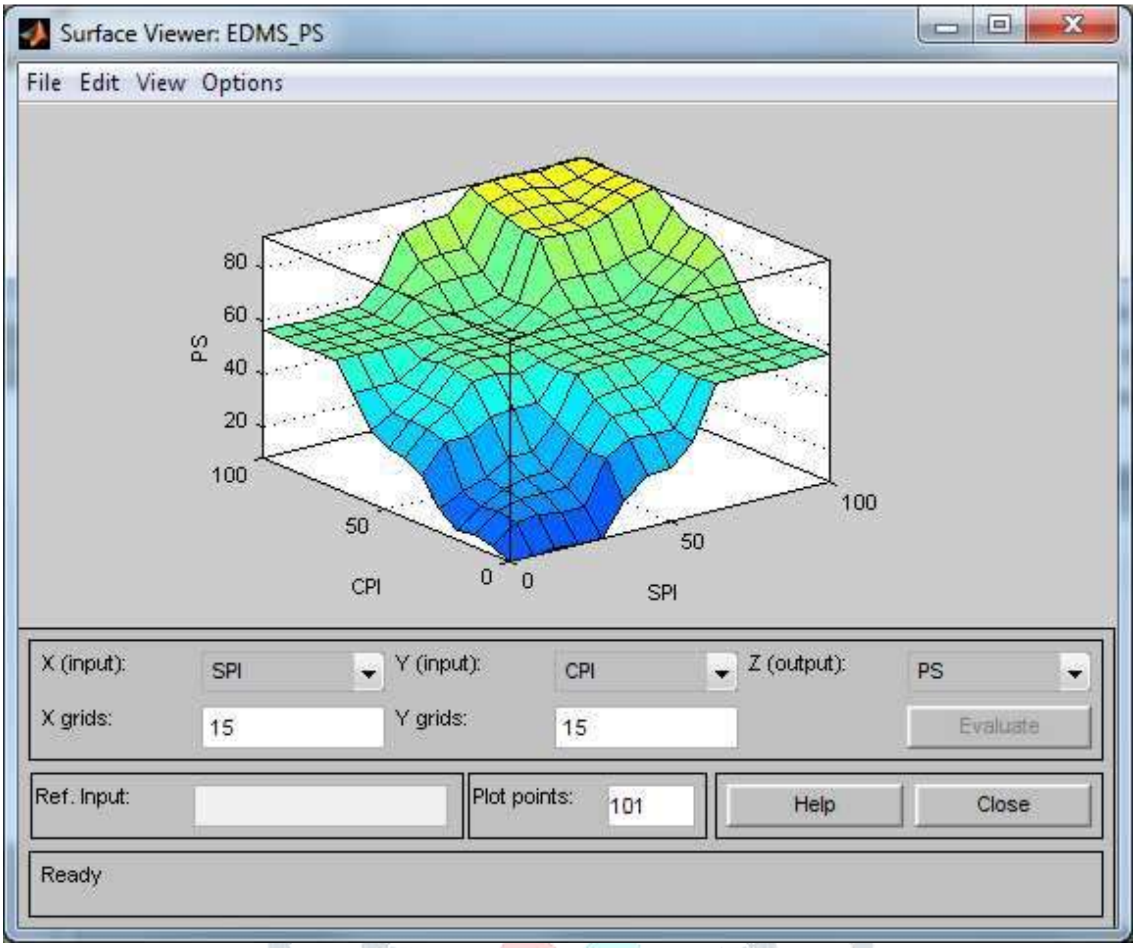


Fig. 9: Correlation between variables (Source: own research)

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.

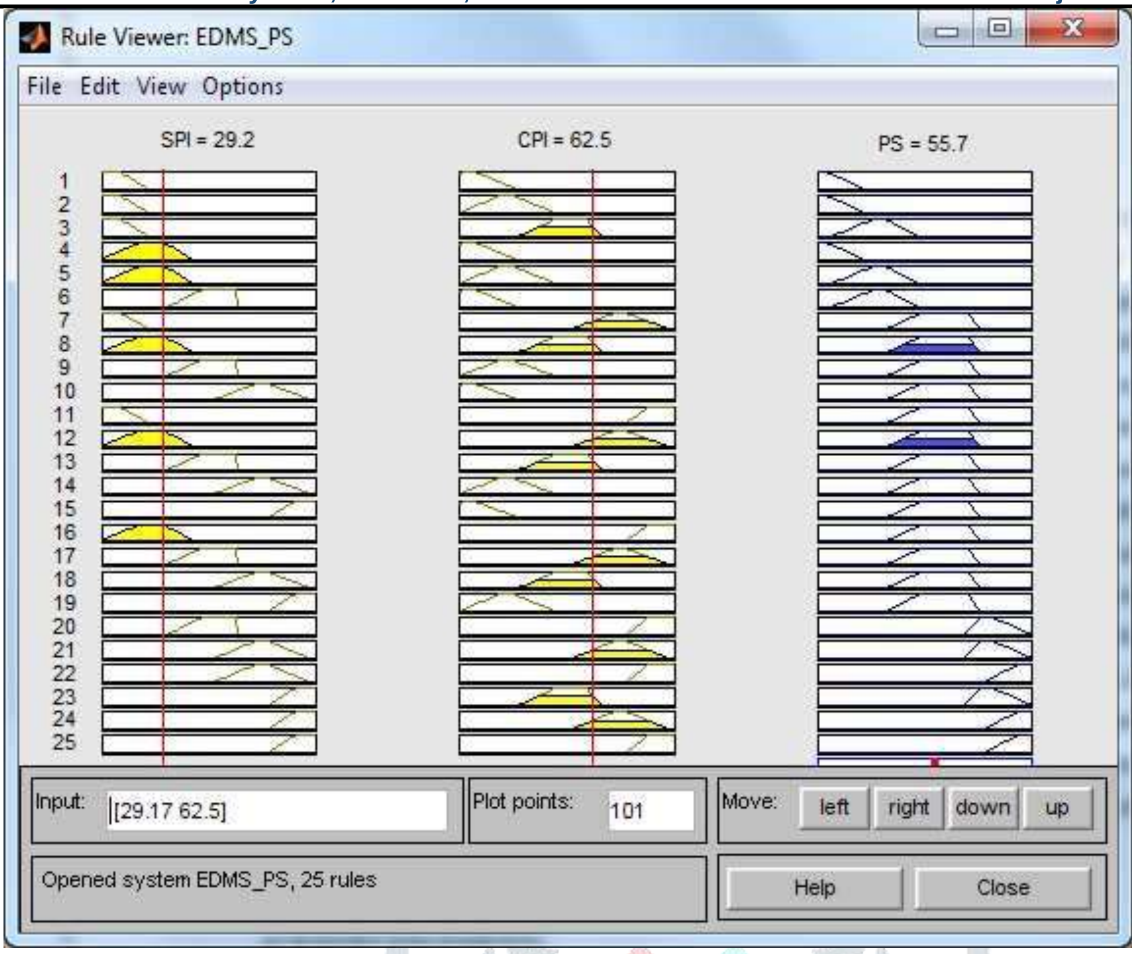


Fig. 10: Validation of the fuzzy model (Source: own research)

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 2019	45.83	25.00	54.55	53.10
End of April 2019	12.50	75.00	54.55	56.10
End of May 2019	29.17	62.50	54.55	55.70
End of June 2020	45.83	41.67	54.55	56.20
End of July 2020	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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