A FUZZY APPROACH TO EVALUATING WORKLOAD AND SCHEDULE PROGRESS FOR CONSTRUCTION PROJECTS DURING THE DESIGN PHASE

[1]CHIA-JUI CHANG, [2]SZU-WEI YU

[1,2]Department of Environment Information and Engineering, CCIT, National Defense University
E-mail: [1]chiarueichang@gmail.com, [2]jameszwyu@gmail.com

Abstract - Owners and contractors typically project progress in different ways, causing disputes and obstructing project implementation. The milestone method is usually used to measure the progress of a project during the planning and design stages. However, this method lacks the ability to quantitatively measure the specific design workload and cannot provide an early warning mechanism for project issues. The main reason for this is the difficulty of using a precise semantic description to evaluate planning and design work. Earned Value Management (EVM) is a common method for project management. Previously, EVM focused on cost management; however, more recently, it has been used successfully in time management. In this study, a fuzzy semantic method, combined with EVM, is developed to quantify design work activities and estimate schedule progress in time performance management. A case study of a simple construction project during the design phase is performed to demonstrate and verify this fuzzy approach.

Keywords - Earned Value Management, Fuzzy Theory, Design Work, Schedule Progress.

I. INTRODUCTION

The four basic baselines of a construction project are scope, schedule, cost, and quality. Each project is an independent and non-repetitive case. Project managers focus on finishing the project workloads on time, complying with the contract's budget and quality standards. The characteristics of scope and schedule for project management are as follows:

1. A project has a fixed workload. At the end of a project, the actual workload and the planned workload should be the same. Scope refers to the range of work. It can be interpreted as measuring the workload involved in a project.
2. At the end of the project, the actual execution time usually differs from the expected execution time. Project time management usually assists in the planning, monitoring, and forecasting of a project's progress.
3. The progress of work is usually treated as the schedule progress in the traditional Earned Value Management (EVM) approach.

The common goal and main task of owners and contractors using project management is to complete a project workload on time. In general, contractors place the emphasis on cost management in order to achieve the goal of greater profit, while owners pay more attention to time management to avoid the impact of delays. *"If cost and schedule are the project goals, their explicit and constant monitoring is necessary"*[1]. However, research reveals that one-third of construction projects miss cost and schedule targets [2].

Eldin [3] concluded that most researchers focused their attention more on the management of the construction phase than the design phase. This is because the cost associated with the design phase is relatively low. However, efficient and effective management during the design phase has a large influence on the entire construction project.

In this study, an approach combining EVM and fuzzy theory is developed to evaluate design workload and schedule progress for construction projects during the design phase. A simple case study is performed to demonstrate and verify this fuzzy approach.

II. RESEARCH PROCESSES

The following is a brief description of the research process for this paper:

1. Literature review of EVM: The review shows that when schedule variance of EVM is used to assess the schedule progress, it will cause confusion in time management. A modified method, Earned Schedule Method (ESM) [4], was introduced in the literature for project schedule performance management.
2. Literature review of fuzzy theory, Fuzzy EVM, and Fuzzy ESM: The review reveals that fuzzy theory can be combined with EVM and ESM for measuring project performance [5, 6]. In this paper, Fuzzy EVM is developed to measure the degree of completeness of the design workload activities, and Fuzzy ESM is used to evaluate the project schedule performance.
3. Design work of construction projects is broken down into types of activities instead of milestones. A simple case study of a construction project for which the design work is broken down into activity types during the design phase is performed. This work demonstrates and verifies the Fuzzy EVM and Fuzzy ESM approaches to

evaluating the amount of work completed and estimating the progress according to the schedule.

III. REVIEW OF EVM IN THE LITERATURE

3.1. Earned Value Management

EVM methodology can be traced back to the agencies of the U.S. federal government in 1967. The Project Management Institute [7] noted that *"earned value management is a methodology that combines scope, schedule, and resource measurements to assess project performance and progress."*

As shown in **Fig. 1**, traditional EVM consists of three factors: Planned Value (PV), Earned Value (EV), and Actual Cost (AC). Schedule Variance (SV) and a Schedule Performance Index (SPI) are used to evaluate the project time performance. When SV > 0 or SPI > 1, then the project is "ahead of schedule". When SV = 0 or SPI = 1, the project is "on schedule". When SV < 0 or SPI <1, the project is "behind schedule". The equations of SV and SPI are defined respectively as follows:

$$SV = EV - PV \quad \text{and} \quad (1)$$

$$SPI = EV / PV. \quad (2)$$

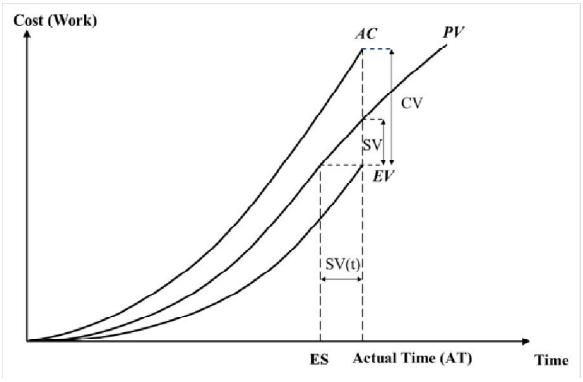

Fig. 1. Measurements of CV, SV, and SV(t) of a combined cost/work and time graph.

3.2. Confusion in Time Performance Measurement

Lipke [4], as well as Vandevoorde and Vanhoucke [8], highlighted the issues that arise when SV is used to measure time performance in traditional EVM:

1. The use of monetary units to measure SV as opposed to time units can be difficult to understand.
2. SV = 0 (or SPI = 1) shows that the ongoing project is on schedule, but it is also used to show that the project has been completed;this can create confusion.
3. At project completion, SV always converges to zero. For projects completed behind schedule, SV = 0 (or SPI = 1) indicates normal progress. This creates a conflict in that the project is both on schedule and overdue.

In the early stages of research, only the cost-forecasting model was developed for EVM. In recent years, a variety of time prediction models have been developed. Lipke [4], Anbari [9], and Jacob [10] proposed time prediction models for an ESM, Planned Value Method (PVM), and Earned Duration Method (EDM), respectively. There have been several studies comparing the time prediction capabilities of the ESM, PVM, and EDM [8, 11–13]. Those comparative studies have shown that ESM as a methodology outperforms both PVM and EDM in terms of accuracy and stability.

ESM measures schedule performance in terms of time on the X-axis. It developed a modified schedule variance, SV(t) = ES − AT (see **Fig. 1**), where ES represents Earned Schedule and AT represents Actual Time. When dealing with S-shaped curves, the exact value of ES corresponding to EV is difficult to ascertain. An approximate method could be used to estimate ES between a unit time interval, N and (N + 1), while EV is completed work between PV_N and PV_{N+1}. The equation to estimate ES is:

$$ES = N + \frac{(EV - PV_N)}{(PV_{N+1} - PV_N)}. \quad (3)$$

The Schedule Performance Index of ESM (SPI_t) is defined as:

$$SPI_t = ES / AT \quad (4)$$

The estimated time at completion of ESM is defined as:

$$EAC_t = AT + \frac{PD - ES}{PF}, \quad (5)$$

where PD represents Planned Duration and PF represents Performance Factor. In this paper, PF = SPI_t is adopted for its clear association with time and how it reflects project schedule performance up to the observation point.

IV. EVALUATION OF WORKLOAD AND SCHEDULE PROGRESSUSING AFUZZY APPROACH

4.1. Difficulties of Time Management during the Design Phase

Anbari [9] interpreted the EV as the actual amount of work done at a certain observation point. Oberlender [14] addressed the following methods that can measure the earned workload of construction projects during the design phase:

1. **Units Completed:** The measure of work can be determined as a percentage that is calculated by dividing the amount of work completed by the total amount of work that needs to be produced.
2. **Incremental Milestone:** This is appropriate for a measure of production drawings or procurement activities that consist of easily recognized milestones.
3. **Start–Finish Percentages:** This is applicable to those activities that lack definable intermediate milestones, or those activities where the effort and time required are difficult to estimate.
4. **Ratio**: This applies to such tasks as project management or project control involved

throughout the project. Such tasks do not have a specific end product.

Chang [1] used "working hours" to measure EV during the design phase of a construction project, which can be categorized as a "Ratio" approach. However, not all design work can be measured accurately in terms of working hours. Some design work has a high workload, but takes less time to complete. On the other hand, some design work has a low workload, but takes more time to accomplish.

Eldin [3] proposed earning rules (shown in**Table 1**), which assign a value to each control point to measure EV during the design phase of a construction project. This can be classified as an "Incremental Milestone" approach. However, the weight of each control point may vary by project. In addition, this method does not apply to design activities that lack definable intermediate milestones.

Control point number	Earning percentage (%)	Description of control point
1	5	Drawing started
2	45	Issued for engineering review
3	20	Checked and signed by engineer
4	5	Checked and signed by project manager
5	20	Client comments incorporated
6	5	Issued for bid/construction
Total	100	

Table 1. Control points and earning rules [3].

The challenge with the "Units Completed" approach is that intangible design efforts cannot be measured. The insufficiency of the "Start–Finish Percentages" approach is that the percentage usually does not give credit for a long-term activity between start and finish, which is detrimental to the work quantification.

If the measurement of EV is not clear, this can often cause disputes between owners and contractors, such as: (1) what is the actual progress of the project and (2) how much is a reasonable amount for the project payment?

Most contracts use a milestone approach to assess the workload during the design phase. This lacks incremental percentages to quantify the progress of work, which can lead to the following difficulties in time management:

1. Lack of quantitative time management data: The project managers can only know whether architectural/engineering (A/E) firms have completed a specific milestone. The lack of time management data(such as SPI_t and EAC_t)prevents managers fromreceiving early warning information to effectively arrange an early response for subsequent works.
2. Lack of a quantitative basis for pricing if there is a change order for work or contract termination occurs: It is difficult to settle disputes with a lack of quantitative work measures.
3. The financial difficulties for A/E firms' cash flow and time management for owners: If a long-term specific milestone fails to be completed, then the A/E firm will not receive service fees for a long period, and the owners cannot earn the schedule progress based on the activities done.

4.2. Fuzzy Theory

Most design work is intangible and cannot be specified, so different managers often describe the degree of completion in different ways.

Zadeh [15] proposed fuzzy theory in 1965, believing that human thinking, reasoning, and cognition of their surroundings often have considerable ambiguity. It explains that uncertainty in events and systems arises due to vagueness or fuzziness rather than randomness alone. Thus, traditional analytical methods that rely on exact numerical values to make predictions and inferences cannot be completely applied to people-centric systems that have variability and complexity issues. The solution is to model and treat the uncertainty using linguistic terms with fuzzy theory.

4.3. Fuzzy EVM

Naeni and Salehipour [5] proposed a modified EVM method based on a fuzzy linguistic. If the progress of an activity cannot be stated with certainty, then using a linguistic phrase to define it is an alternative approach. Then, the method needs to convert linguistic terms into fuzzy numbers by applying fuzzy principles. This modified method incorporated fuzzy principles into EV calculations, and evaluation of schedule progress.The calculation process for fuzzy EVM is described as follows:

1. A project has many activities.
2. For each activity, PV and AC are the determined values. However, owners and contractors usually have different perspectives on EV calculations.
3. The EV of each activity can be given by a subjective opinion. Because of the uncertainty of subjective opinions,it is suggested to use fuzzy numbers to give a subjective rating in linguistic way.
4. Calculate the EV of the project by multiplying the completion amount (workload) and budget of each activity.
5. Evaluate the project performance usingthe EVM and ESM approaches, where PV and AC are the determined values, and EV is a fuzzy number.

Naeni and Salehipour [5] used a fuzzy membership including trapezoidal and triangular fuzzy numbers.In this paper, atriangular fuzzymembership number to assign each activity a set of fuzzy numbers is used in order to simplify the calculation. Shown in**Fig.2**, a triangular fuzzy number of a set is a membership

function written as $F_A(x) = (a_1, a_2, a_3)$, which produces values in the range [0, 1] for all x. It is defined by three numbers, $a_1 \le a_2 \le a_3$, where the base of the triangle is the interval $[a_1, a_3]$ (membership is equal to zero), and the vertex is a_2 (membership is equal to one).
In this paper, the linguistic terms of triangular fuzzy numbers are divided into seven levels from "Not started" to "Finished"to describe the degrees of work completion. **Figure 3** and **Table 2** show the degrees of work completion corresponding to the triangular fuzzy number.

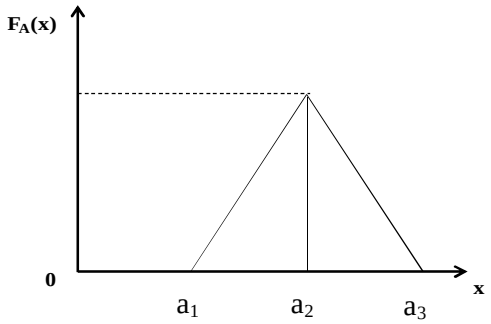

Fig. 2. Triangular fuzzy number.

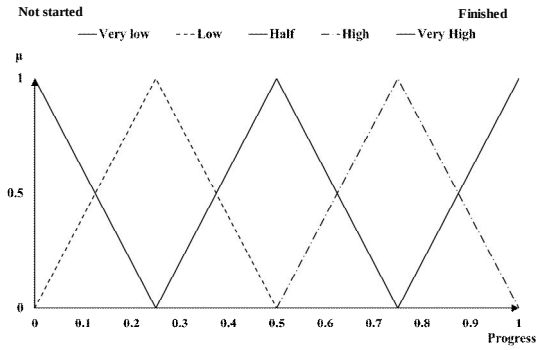

Fig. 3. Triangular fuzzy membership numbers and the corresponding linguistic terms.

Linguistic term	Fuzzy number		
Not started	0	0	0
Very low	0	0	0.25
Low	0	0.25	0.5
Half	0.25	0.5	0.75
High	0.5	0.75	1
Very High	0.75	1	1
Finished	1	1	1

Table 2. The fuzzy numbers assigned to each linguistic term in Fig. 3.

For the calculation of a fuzzy number, the basic operations of two fuzzy numbers are defined as follows:

$$\tilde{m} + \tilde{n} = [m_1 + n_1,\ m_2 + n_2,\ m_3 + n_3], \quad (6)$$

$$\tilde{m} - \tilde{n} = [m_1 - n_3,\ m_2 - n_2,\ m_3 - n_1], \quad (7)$$

$$\tilde{m} \times \tilde{n} = [m_1 \times n_1,\ m_2 \times n_2,\ m_3 \times n_3], \text{ and} \quad (8)$$

$$\tilde{m} \,/\, \tilde{n} = [m_1/n_3, m_2/n_2, m_3/n_1]. \quad (9)$$

Using a fuzzy linguistic of EVM, the steps of a fuzzy EV calculation are described as follows:

1. Give the activity i a fuzzy number,$\tilde{F}_i$, based on fuzzy completion percentage from **Table 2**:

$$\tilde{F}_i = [a_{1i}, a_{2i}, a_{3i}]. \quad (10)$$

2. Calculate the EV of activity i,$\widetilde{EV}_i$, by multiplying the completion level of $\tilde{F}_i$and the budget of BAC_i, which is the budget at the completion of activity i:

$$\widetilde{EV}_i = \tilde{F}_i * BAC_i = [EV_{1i}, EV_{2i}, EV_{3i}]. \quad (11)$$

3. Sum up all $\widetilde{EV}_i$ to derive the total fuzzy EV in each measurement period, where n is the total number of project activities:

$$\widetilde{EV} = \sum_{i=1}^{n} \widetilde{EV}_i = [EV_1, EV_2, EV_3]. \quad (12)$$

For the measure of project time performance and duration forecasting, this study believes that the unit of progress for the schedule should be a time unit, in line with the physical meaning of time management. Furthermore, in order to avoid confusion with time management mentioned in **Section 3.2**,ESM is used to measure earned time of the X-axis with respect to EV of the Y-axis in this study.

The steps for using the fuzzy linguistic of ESM are as follows:

1. The fuzzy ES of each activity is calculated according to the concept used to develop **Eq. (3)**, where$N$ denotes the observation period and j (=1, 2, 3) represents the fuzzy set number of each fuzzy ES:

$$ES_j = N_j + \frac{EV_j - PV_{Nj}}{PV_{Nj+1} - PV_{Nj}}, j = 1, 2, 3 \text{ and} \quad (13)$$

$$\widetilde{ES} = [ES_j] = [ES_1, ES_2, ES_3]. \quad (14)$$

2. Calculate the fuzzy schedule performance index according to the concept used to develop**Eq. (4)**:

$$\widetilde{SPI}_t = \frac{\widetilde{ES}}{AT} = [\frac{\widetilde{ES}_1}{AT}, \frac{\widetilde{ES}_2}{AT}, \frac{\widetilde{ES}_3}{AT}]. \quad (15)$$

3. Estimate the time at the completion of a project according to the ES-based concept used to develop**Eq. (5)**:

$$\widetilde{EAC}_t = \frac{PD}{\widetilde{SPI}_t} = \left[\frac{PD*AT}{ES_3}, \frac{PD*AT}{ES_2}, \frac{PD*AT}{ES_1}\right]. \quad (16)$$

When the performance indicators or forecast results of the actual value management are fuzzy sets, they are difficult for managers to use for project performance management. There are several defuzzification methods that can be used to obtain a definite value, such as the α-cut [5], the bary centric rule [6], and the Graded Mean Integration Representation(GMIR) methods[16]. In this study, the GMIR method is adopted, where the original fuzzy set is (a_1, a_2, a_3):

$$\text{Defuzzification} = (a_1 + 4\,a_2 + a_3) / 6. \quad (17)$$

After defuzzification, project managers can determine the degree of work completeness from the value of EV, project schedule performance from the value of SPI_t,

and the estimated time at completion from the value of EAC_t. The interpretations of the defuzzificated schedule performance index are shown in **Table 3**.

Status	Interpretation
$SPI_t > 1$	Ahead of schedule
$SPI_t = 1$	On schedule
$SPI_t < 1$	Behind schedule

Table 3: Interpretations of the schedule performance index.

V. CASE STUDY

In this section, a simple overdue situation is used to demonstrate the calculations for the Fuzzy EVM and Fuzzy ESM approaches. The design contract of a design–bid–build project can be divided into five stages: (1) Preliminary Design, (2) Detailed Design, (3) Construction Procurement, (4) Half Completion of Construction, and (5) Acceptance of Work. **Table 4** summarizes the proportion of service costs for each stage. The ratio of service costs to total contract price can be used as the weight of the design workload for each stage. The preliminary design stage is used to demonstrate and verify the fuzzy approach developed in this study to estimate workload and schedule progress.

	Work Item	Cost %	Detail Work	Cost %
1	Preliminary Design	20	Site Investigation	3
			Collect Requirements	2
			Design Concept	2
			Basic Design Report	5
			Base Surveying	4
			Geological Prospecting	4
			Total	20
2	Detailed Design	20		
3	Construction Procurement	35		
4	Half Completion of Construction	10		
5	Acceptance of Work	15		
	Total	100		

Table 4. Work items and cost population of a preliminary design case.

In the preliminary design stage, the planned duration for this is5 months, and the design work is measured by the following activities: (1) Site Investigation, (2) Collect Requirements, (3) Design Concept, (4) Basic Design Report, (5) Base Surveying, and (6) Geological Prospecting. The quantitative measure of each activity is its percentage of cost to the contract total cost.

The planned duration of each activity is shown in the bar chart of **Table 5**. Each of the preliminary design activities can be decomposed into more detailed tasks. For example,"Site investigation" can be decomposed into five tasks, such as Environmental Assessment, Hydropower Pipeline Information Survey, Permit Requirements, Submission of Site Investigation Result, and Approval of Site Investigation Result.

Tables 6 and **7**, using the third time period (AT = 3) as an example, show the calculation processes for Fuzzy EVM and Fuzzy ESM, respectively. Note that not all of the measures of design activities require fuzzy measuring. For example, the workloads for "Base Surveying" measured by area or "Geological Prospecting" measured by depth can be measured by units completed.

The results of using Fuzzy ESM to evaluate the project schedule performance for each observation time of this overdue project during the design phase are summarized in **Table 8**. With the GMIR method, the defuzzificated schedule performance index (SPI_t) and the defuzzificated estimated duration (EAC_t) are also shown in **Table 8**. In this overdue case, SPI_t is always less than 1.0 until the project is completed in the sixth month. Hence, the use of SPI_t to measure the schedule performance correctly reveals the project is behind schedule. On the fourth and fifth months of this overdue project, the Fuzzy ESM approach can appropriately predict that the project will be completed around the sixth month (EAC_t = 6.25 or 5.58).

	Preliminary design activities	Detailed tasks	1	2	3	4	5
1	Site Investigation						
		Environmental Assessment					
		Hydropower Pipeline Information Survey					
		Permit Requirements					
		Submission of Site Investigation Result					
		Approval of Site Investigation Result					
2	Collect Requirements						
3	Design Concept						
4	Basic Design Report						
5	Base Surveying						
6	Geological Prospecting						

Table 5: Planned durations in the preliminary design stage.

Activity	BAC	Progress	F_i Fuzzy nubmers			EV_i Fuzzy nubmers		
Site Investigation								
Environmental Assessment	0.6	Very High	0.75	1	1	0.45	0.60	0.60
Hydropower Pipeline Information Survey	0.45	Very High	0.75	1	1	0.34	0.45	0.45
Permit Requirements	0.45	Half	0.25	0.5	0.75	0.11	0.23	0.34
Submission of Site Investigation Result	0.9	Half	0.25	0.5	0.75	0.23	0.45	0.68
Approval of Site Investigation Result	0.6	Low	0	0.25	0.5	0.00	0.15	0.30
Collect Requirements	2	Low	0	0.25	0.5	0.00	0.50	1.00
Design Concept	2	Low	0	0.25	0.5	0.00	0.50	1.00
Basic Design Report	5	Low	0	0.25	0.5	0.00	1.25	2.50
Base Surveying	4	60%				2.40	2.40	2.40
Geological Prospecting	4	45%				1.80	1.80	1.80
Total	20					5.33	8.33	11.06

Table 6: Calculation results in preliminary design stage using Fuzzy EVM when AT = 3.

j	EV_j	N_j	EV_j-PV_{Nj}	PV_{Nj+1}-PV_{Nj}	ES_j
1	5.33	1	1.78	3.85	1.46
2	8.33	2	0.93	5	2.19
3	11.06	2	3.66	5	2.73

Table 7: Calculation results for Fuzzy ES in preliminary design stage when AT = 3.

t	1	2	3	4	5	6
PV	3.55	7.4	12.4	18	20	
$\widetilde{EV}$	(1.64,1.9,2.05)	(2.79,3.39,6.13)	(5.33,8.33,11.06)	(10.8,13.8,16.2)	(17.8,19.2,19.2)	(20,20,20)
EV	1.88	3.74	8.28	13.7	18.97	20
$\widetilde{ES}_t$	(0.46,0.54,0.58)	(0.79,0.95,1.67)	(1.46,2.19,2.73)	(2.68,3.25,3.68)	(3.96,4.6,4.6)	(5,5,5)
$\widetilde{SPI}_t$	(0.46,0.54,0.58)	(0.39,0.48,0.84)	(0.49,0.73,0.91)	(0.67,0.81,0.92)	(0.79,0.92,0.92)	(0.83,0.83,0.83)
SPI_t	0.53	0.52	0.72	0.81	0.9	0.83
$\widetilde{EAC}_t$	(8.66,9.34,10.82)	(5.99,10.47,12.72)	(5.49,6.86,10.26)	(5.44,6.15,7.46)	(5.43,5.43,6.31)	(6,6,6)
EAC_t	9.48	10.1	7.2	6.25	5.58	6

Table 8: Calculation results in preliminary design stage using Fuzzy EVM.

CONCLUSIONS

Efficient and effective management during the design phase has a great influence on the entire construction project. However, in academic studies orin practice, efforts have typically focused on the study of management during the construction phase. One of the reasons for the lack of time management research for the design phase in the literature is the difficulty in measuring design workload in a quantitative way.

In this study, we developed an earned value management approach based on fuzzy theory to calculate design workload and an earned schedule method approach based on fuzzy theory to evaluate the project's schedule progress. A case study of a simple construction project during the design phase was performed to demonstrate and verify this fuzzy approach. It showed that the design work can be broken down into activities, and the amount of completeness can be either measured by fuzzy numbers, if it is an intangible workload that is appropriate to measure in a fuzzy way, or by definite numbers, if it is a tangible workload and can be measured by units completed. This study demonstrated a preliminary success in the feasibility of using a fuzzy approach to evaluating workload and schedule progress for construction projects during the design phase. Further development using the fuzzy approach to measure design workload and schedule progress in practice, as well as its application to the construction phase, could be a future research topic.

REFERENCES

[1] Chang, A. S., "Defining Cost/Schedule Performance Indices and Their Ranges for Design Projects", Journal of Management in Engineering, 17(2), 122–130, 2001.

[2] Anderson, S. D. and Tucker, R. L., "Improving Project Management of Design", Journal of Management in Engineering, 10(4), 35–44, 1994.

[3] Eldin, N. N., "Management of Engineering/Design Phase", Journal of Construction Engineering and Management, 117(1), 163–175, 1991.

[4] Lipke, W., "Schedule is Different", The Measurable News,pp. 31–34, 2003.

[5] Naeni, M. L. and Salehipour, A., "Evaluating Fuzzy Earned Value Indices and Estimates by Applying Alpha Cuts", Expert Systems with Applications, 38(7), 8193–8198, 2011.

[6] Ponz-Tienda, J. L., Pellicer E., and Yepes, V., "Complete Fuzzy Scheduling and Fuzzy Earned Value Management in Construction Projects", Journal of Zhejiang University SCIENCE A, 13(1), 56–68, 2012.

[7] Project Management Institute, *A Guide to the Project Management Body of Knowledge*, 5th Ed., Newtown Square, PA, 2013.

[8] Vandevoorde, S. and Vanhoucke, M., "A Comparison of Different Project Duration Forecasting Methods Using Earned Value Metrics", International Journal of Project Management, 24(4), 289–302, 2006.

[9] Anbari, F. T., "Earned Value Project Management Method and Extensions. Engineering Management Review", IEEE, 32(3), 97–97, 2004.

[10] Jacob, D., "Forecasting Project Schedule Completion with Earned Value Metrics", The Measurable News, 7–9, 2003.

[11] Batselier, J. and Vanhoucke, M., "Evaluation of Deterministic State-of-the-art Forecasting Approaches for Project Duration Based on Earned Value Management", International Journal of Project Management, 33(7), 1588–1596, 2015.

[12] Vanhoucke, M. and Vandevoorde, S., "A Simulation and Evaluation of Earned Value Metrics to Forecast the Project Duration", Journal of Operation Research Society, 58(10), 1361–1374, 2007.

[13] Wauters, M. and Vanhoucke, M., "Study of the Stability of Earned Value Management Forecasting", Journal of Construction Engineering and Management, 10.1061/(ASCE)CO.1943-7862.0000947, 04014086, 2014.

[14] Oberlender, G. D., *Project Management for Engineering and Construction*, 3rd Ed.,McGraw-Hill, New York, 2014.

[15] Zadeh, L.A., "Fuzzy Sets", Information and Control, 8(3), 338–353, 1965.

[16] Chen, S. H. and Hsieh, C. H., "Representations, Ranking, Distance, and Similarity of L-R Type Fuzzy Number and Application", Australian Journal of Intelligent Information Processing Systems, 6(4), 217–229, 2000.

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