World Applied Sciences Journal 3 (4): 684-690, 2008
ISSN 1818-4952

Applying Fuzzy Control Chart in Earned Value Analysis: A New Application

Siamak Noori, Morteza Bagherpour and Abalfazl Zareei

Department of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran

Abstract: As it is common in project management context, Earned value analysis usually integrates time and cost performance within the project scope. It helps the project manager to understand how to deal with project from two points of view. The first is to recognize current performance indexes and the second one is to provide a forecast to the future. However, most of decisions in this regard have taken based on Schedule Performance Index (SPI) and Cost Performance Index (CPI) while there is no a well organized control mechanism in which detect their situations as it is, not only numerically but also recognize/categorize current situation of the earned value management system linguistically. In this paper a fuzzy control chart approach associated with α-cut is presented in order to control earned value performance indexes including linguistics terms. Also a new application, based on a Multi Period-Multi Product (MPMP) production control problem is illustrated and successfully implemented.

Key word: Earned value analysis . fuzzy control chart . linguistic term . production control problem

INTRODUCTION

Earned value management system assists to a simultaneous time and cost control system to be conducted in accordance with project scope. As it is common in project management context, earned value method is applied in order to accomplish project on time-on budget with acceptable level of quality. In this regard, two performance indexes called as Schedule Performance Index (SPI) and Cost Performance Index (CPI) to be taken which frequently used in earned value management and metrics. Traditionally, SPI and CPI can be calculated by dividing Earned Value (EV) on Planned Value (PV) and Actual Cost (AC) respectively. It is therefore desirable if SPI/CPI would be equal to one. In case of achieving a higher than 1 for both indexes, it means that project performance from both indexes point of view is appropriate and consequently the project will be finished with less required budget sooner that expected in comparison with planned start time. However, in case of being over budget or requiring additional duration more than initial planned duration, where SPI/CPI are less than one, project situation is not proper and it should be taken into consideration for further preventive actions in which assist managers to follow up the project in near future much more better than before in order to achieve project objectives effectively. The most important question here is how to deal with earned value metrics (SPI, CPI) and how can we detect a control mechanism for those mentioned metrics. This problem becomes more important where those indexes to be controlled periodically in order to recognize project situation. By this reason, in this paper, a novel approach based on fuzzy control chart approach is proposed in which implements a control mechanism on earned value metrics. It certainly assists the project managers to deal with project performance and enable them to provide a better forecast accordingly.

Review on fuzzy control chart: The first control chart was proposed by Shewhart [1] in 1920s which is still subject to new application areas. Further developments to improve the performance of control charts proposed by Shewhart [1] are on the basis of usage of probability and fuzzy set theory integrated with the control charts [2]. Fuzzy set theory is required to model type of uncertainty which probability in not capable of modeling [3]. A stochastic decision method such as statistical decision analysis does not measure the imprecision in human behavior; on the other hand, fuzzy set theory captures the subjectivity of human behavior.

The classical judgment in control charts are based on binary classification as “in-control ” or “out-of-control” while in fuzzy control charts several intermediate decisions such as “rather-in-control” or “rather-out-of-control” may be handled in order to cover linguistic terms that in classical control charts could not applied easily.

Corresponding Author: Dr. Siamak Noori, Department of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran

Marcucci [4] proposed two procedures using Shewhart-type control charts for linguistic terms. The first type is designed to detect changes in any of the quality proportions using Pearson statistic (χ^2) and the second type depends upon multinomial distribution, which can be approximated by a multivariate normal distribution and is designed to detect only increases in all but one of quality proportions. Wang and Raz [5] described an approach that can be assigned fuzzy sets to each linguistic term and then combined for each sample using fuzzy arithmetic. The sensitivity of performance of control charts was found to be influenced by the number of linguistic terms used in classifying the observations [6]. In control charts proposed by Kanagave *et al*. [7] for process average and process variability, the probability distribution exists behind the linguistic data was taken into consideration. Taleb and Limam [8] proposed the comparison of fuzzy and probability approaches of constructing fuzzy control charts based on average run length. Cheng [9] proposed the method of constructing a fuzzy control chart for a process with fuzzy outcomes. Fuzzy outcomes, in his paper, described in fuzzy numbers based on experts' quality ratings. Gulbay *et al*. [2] developed α-cut control charts for attributes. In their approaches the tightness of the inspection can be defined by selecting a suitable α-cut. Cheng [10] proposed fuzzy control charts constructed by fuzzy outcomes derived from the subjective quality ratings provided by a group of experts. Gulbay and Kahraman [11] presented some contributions to fuzzy control charts base on fuzzy transformation methods which are made by utilization of α-cut. The α-cut provides an ability to determine the tightness of the inspection properly. They developed an alternative approach namely "Direct Fuzzy Approach (DFA)" which does not require the use of defuzziffication and compare the linguistic data in fuzzy space without making any transformation. Faraz and Moghadam [12] proposed a fuzzy control chart for process average of a continuous quality characteristic and through an example; they proved that it is a better alternative to Shewhart $\overline{X}$ chart.

Literature review on earned value analysis: Related researches which had been carried out in earned value mostly focused on application of earned value method in different projects as well as organizations. The other category also provided an insight to earned value development which earned value parameters was taken into considerations. As a closely related research, Anbari [13] provided an excellent insight to earned value management method and also proposed a simple control limit for earned value metric. He considered simple numerical control limits as caution and poor area for evaluating SPI/CPI indexes respectively. However, he did not provide more detail for intermediate SPI/CPI amounts.

As a recent work, Vandevoorde and Vanhoucke [14] not only focused on traditional earned value metrics, but also they developed earned schedule performance indicator namely SV(t) and SPI(t). Their proposed approach also was able to yield forecast total project duration. Moreover, their developed formula compared with three available methods in the literature based on testing three real life projects in several situations. Finally, they concluded the superiority of the proposed approach. However, they recommended that maybe based on situation e.g. project manager knowledge and project management team other methods also would be useful.

Vitner *et al*. [15] applied a Data Envelopment Analysis (DEA) in order to performance evaluation in a multi project environment where each project has been defined uniquely. They integrated both Earned Value Management System (EVMS) and Multi Denominational Control System (MPCS). They also provided a new approach in order to reduce number of inputs and outputs in their developed approach to get better results in multi project environment. However, they pointed out, it was for the first time that DEA had been applied in project environment where it has been previously used in organizations e.g. hospital, banking etc.

Cioffi [16] presented a new formalism notations used in earned value analysis and reproduced standard earned value parameters. He also presented additional quantities defined there. He pointed out that his proposed approach can accomplish because of several objectives e.g. earned value analysis can be used faster, easier, more frequently and more useful especially for non linear prediction.

Prior to this work, Cioffi [17] presented an analytical parameterization for S-curve where the curves were normalized two basic parameters. However, it can be further used for earned value analysis when the curve appropriately fitted.

Kim *et al*. [18] developed a model based on research conducted on a two year period in different types of projects and organizations e.g. public and private organizations as well as large and small projects. Firstly, they discussed the problems arising during earned value implementation e.g. too much cost and paper work. Secondly as another finding, based on their conceptual model, it is necessary to consider four group namely earned value users, EV methodology, implementation process and project environment together. As a major conclusion, they expressed that in order to implement earned value method; it is not simple to introduce a methodology in an organization. Instead it should be embedded with overall organizational approaches such as "colleague-based organizational culture, continuing top-level management attention" and facilitating supporting systems e.g. project management office.

Moslehi *et al*. [19] presented an integrated web based time and cost control system for construction projects which mapped Work Breakdown Structure (WBS) in to an object oriented model to enable generate earned value reports at control objects, resource levels. Moreover, in order to analyze project variance, a set of resource performance indicators used. This system also assists to share data in within a world wide web.

Al-Jibouri [20] evaluated effectiveness of three monitoring systems namely leading parameters technique, variance method and activity based ratio technique in construction projects from both theoretical and experimental point of view. Their investigations indicated that activity based ration and variance method have a better performance than leading parameter technique. Also, they introduced activity based ratio a faster and simpler method in comparison with other two approaches. However, they pointed out that it is difficult to generalize the results found on their investigation and further it can be customized based on the nature of project and amount of information required for further actions.

Stratton [21] discussed applying earned schedule analysis in order to estimate completion date. Firstly, he presented commonly earned value technique including Schedule Performance Index (SPI) and then SPI (t) that can be estimated based on dividing earned schedule on actual time where earned schedule can be calculated based on mapping earned value amount on time (horizontal) axis.

As it is well indicated, although there are some researches about both earned value analysis and (fuzzy) control chart, no related research found in which applied both control chart and earned value analysis simultaneously even deterministically. However, in this paper, a fuzzy control chart is developed to manage earned value metrics e.g. SPI, CPI. The manager here is able to use intermediate decision levels as well as traditional control levels.

PROPOSED FUZZY CONTROL CHART THROUGH EANRED VALUE ANALYSIS

Anbari [13] presented a control chart called "Target Performance Chart" for evaluating CPI, SPI and consequently Critical Ration (CR). He divided the performance index through four parts namely poor, caution, good, super star. However, judgment in control chart proposed by Anbari [13] was mostly based on binary classification. To expand above mentioned judgment for further intermediate linguistic decisions, a fuzzy control chart is proposed based on α-cut which several intermediate decisions as "rather-poor", "rather-caution", "rather-good" and "rather-super-star" can be taken into consideration (Fig. 1). Control chart is designed in such a way that when a=1, the control chart is the same as traditional one as Anbari [13] proposed and when a=0, only the intermediate decisions can be traced. The value of α-cut represents the tightness of inspection and can be defined by the project manager or the experts' experience while the higher value of a represents both tighter inspection or the control chart tends to classical case. In Fig. 1, the proposed fuzzy control chart is illustrated.

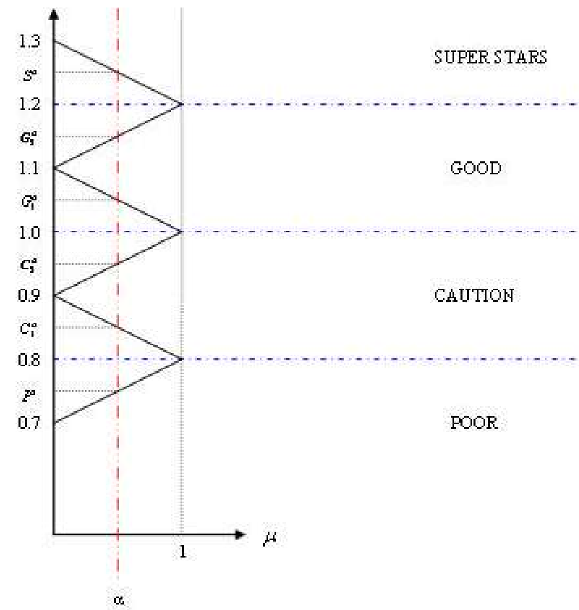

Fig. 1: Fuzzy control chart based on α-cut

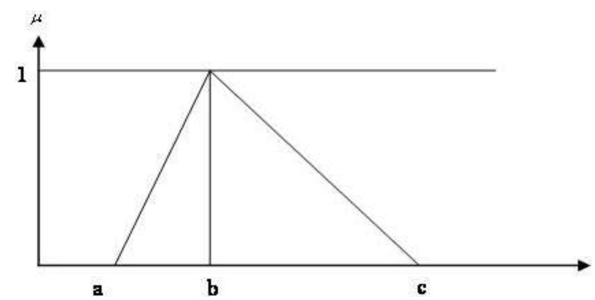

Fig. 2: Triangular fuzzy number (a,b,c)

In classical control chart proposed by Anbari [13] the condition areas are divided by crisp numbers as 0.8,

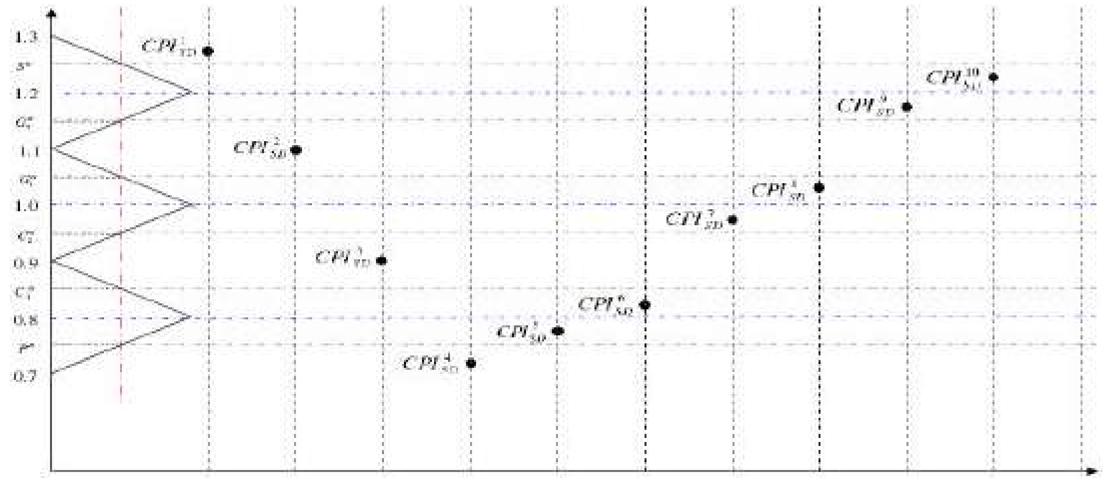

Fig. 3: Samples of CPI_{SD}

Table 1: CPI status date

CPI_{SD}	Process decision
$CPI_{SD} \geq S^{\alpha}$	Super stars
$G_1^{\alpha} \leq CPI_{SD} \leq G_2^{\alpha}$	Good
$C_1^{\alpha} \leq CPI_{SD} \leq C_2^{\alpha}$	Caution
$CPI_{SD} \leq P^{\alpha}$	Poor
$G_2^{\alpha} \leq CPI_{SD} \leq S^{\alpha}$	$\beta_1 = \frac{CPI_{SD} - G_2^{\alpha}}{S^{\alpha} - G_2^{\alpha}}$
$C_2^{\alpha} \leq CPI_{SD} \leq G_1^{\alpha}$	$\beta_2 = \frac{CPI_{SD} - C_2^{\alpha}}{G_1^{\alpha} - C_2^{\alpha}}$
$P^{\alpha} \leq CPI_{SD} \leq C_1^{\alpha}$	$\beta_3 = \frac{CPI_{SD} - P^{\alpha}}{C_1^{\alpha} - P^{\alpha}}$

1.0 and 1.2 while in fuzzy control chart proposed in this paper, the control limits are defined by triangular fuzzy number as 0.8, 1.0 and 1.2 which are determined as given in following equations (Note that a triangular fuzzy number is introduced by the notation (a, b, c) as shown in Fig. 2):

$$1.2 = (1.1, 1.2, 1.3) \quad (1)$$

$$1.0 = (0.9, 1.0, 1.1) \quad (2)$$

$$0.8 = (0.7, 0.8, 0.9) \quad (3)$$

By determining the value of a, control limits are calculated by the following equations:

$$0.8^{\alpha} = [P^{\alpha}, C_1^{\alpha}] = [0.7 + 0.1\alpha, 0.9 - 0.1\alpha] \quad (4)$$

$$1.0^{\alpha} = [C_2^{\alpha}, G_1^{\alpha}] = [0.9 + 0.1\alpha, 1.1 - 0.1\alpha] \quad (5)$$

$$1.2^{\alpha} = [G_2^{\alpha}, S^{\alpha}] = [1.1 + 0.1\alpha, 1.3 - 0.1\alpha] \quad (6)$$

Following, method of utilizing the proposed fuzzy control chart to make decision about the process condition based on CPI index is presented. It is obvious; the method proposed for CPI index can also be used for SPI index.

The condition of process control after calculating CPI in status date (CPI_{SD}) can be stated as below (Table 1).

Alternatively, for a CPI_{SD} which β_i is calculated, the value of β_i can be compared to a predefined acceptable percentage (β) and decisions can be made as follow:

If $\beta_1 \geq \beta$, it is "rather super star" Else it is "rather good".
If $\beta_2 \geq \beta$, it is "rather good" Else it is "rather caution".
If $\beta_3 \geq \beta$, it is "rather caution" Else it is "rather poor".

Note that the value of β can subjectively be defined by the experts' experiences or directly by the project manager. When β=1, the process control decision results in "poor" or "caution" or "good" or "super-star" and as β approaches to 1,the tightness of inspection increases. In Fig. 3, process control decisions for some examples are presented.

Assume that β= 0.5, *CPI* samples illustrated in Fig. 3 results in ten types of different decisions: CPI_{SD}^1 : "super-star", CPI_{SD}^2 : "good", CPI_{SD}^3 :"caution", CPI_{SD}^4 : "poor", CPI_{SD}^5 :"rather-poor"(the value of β_3 is less than β), CPI_{SD}^6 :"rather-caution"(the value of β_3 is more than β), CPI_{SD}^7 :"rather-caution"(the value of β_2 is less than β), CPI_{SD}^8 :"rather good"(the value of β_2 is

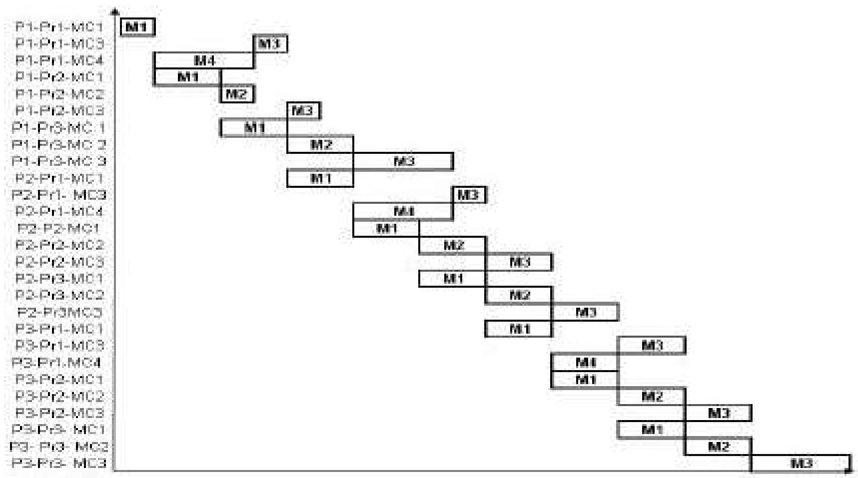

Fig. 4: Detailed time schedule for case study

more than β), CPI_{SD}^{9} :"rather-good"(the value of β_1 is less than β), CPI_{SD}^{10} :"rather-super-star"(the value of β_1 is more than β).

A NEW APPLICATION TO A MULTI PERIOD-MULTI PRODUCT PRODUCTION PLANNING PROBLEM

Here, a case study given in [22-24] is initially used. That is why; in their study only production planning data had been observed. Thus, corresponding data to actual costs and also earned value amount based on achieved progress is then added in this paper. Hereby, based on data observed in multi period-multi product production planning problem, a detailed time schedule is constructed as given in Fig. 4.

In above time schedule, activities to be done in a specific period, product and machine center have been shown. The horizontal axis also indicates required completion time.

Since time schedule has prepared, Planned Value (PV) and consequently Earned Value amount (EV) can be easily calculated. Actual costs of work performed based activity level also added in order to make a meaningful earned value analysis.

In given example, CPI and SPI values are calculated and shown in proposed control chart (Fig. 5) up to status date (tenth day). Relevant decisions about process conditions will be determined as follows: (Assume that predefined acceptable percentage value (β) is equal to 0.5)

CPI in status day is equal to 0.832. Assume a = 0.5, referring to Table 1, the value of β_3 should be calculated in order to make a decision about the process condition. The value of β_3 is calculated as follow:

Table 2: The status of earned value metrics

	Values	Process decision
CPI_{SD}	0.832	Rather caution
SPI_{SD}	0.752	Rather poor

$$\beta_3 = \frac{CPI_{SD} - P^{\alpha}}{C_1^{\alpha} - P^{\alpha}} = \frac{0.832 - 0.75}{0.85 - 0.75} = 0.82 \qquad (7)$$

Comparing obtained value of β_3 with value of predefined acceptable percentage (β), will yield a "rather caution" decision.

SPI value in status date is equal to 0.752 which referring to Table 1, value of β_3 should be calculated and compared with β value:

$$\beta_3 = \frac{SPI_{SD} - P^{\alpha}}{C_1^{\alpha} - P^{\alpha}} = \frac{0.752 - 0.75}{0.85 - 0.75} = 0.02 \qquad (8)$$

Schedule performance condition is therefore determined as "rather poor".

CPI and SPI values in status date and related process decisions are shown in Fig. 6 and Table 2 respectively.

CONCLUSION REMARK AND FURTHER INVESTIGATIONS

In this paper a novel approach based of fuzzy control chart concept is proposed in order to control SPI/CPI trend in earned value method while previously developed version was only focused on four crisp simple control limit and no attention to intermediate linguistic terms had been carried out. Since project management can be efficiently applied in different

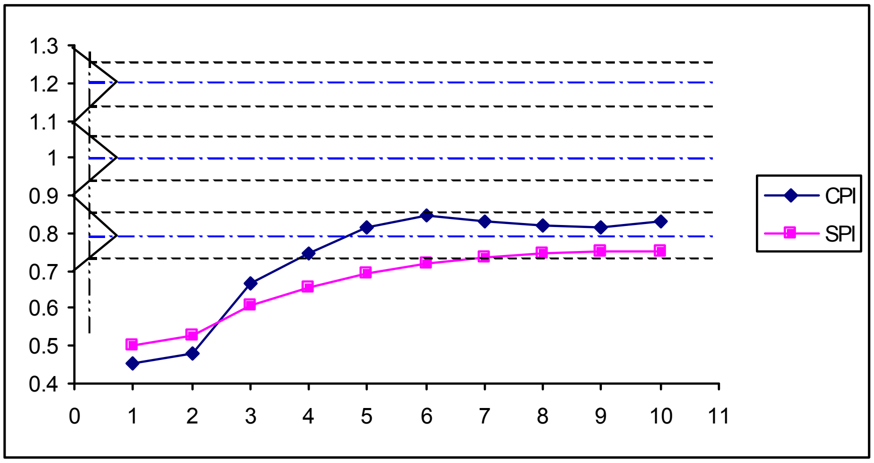

Fig.5: CPI and SPI in fuzzy control chart until the status date

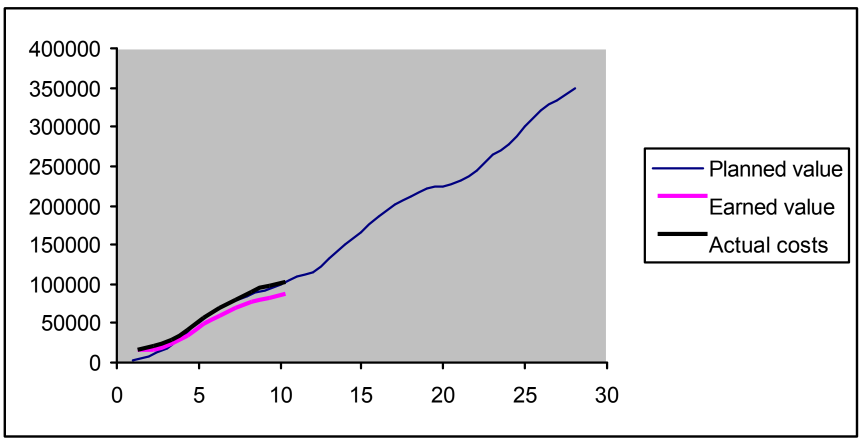

Fig.6: Earned value analysis

cases, it would be highly desirable to conduct such a widely developed approach for controlling corresponding matrices. The approach also implemented successfully in a manufacturing environment, where the reader can easily make a sense about production status and consequently adapt it using earned value analysis accordingly.

Further investigations can be done by applying stochastic process in earned value analysis in order to detect earned value control mechanism as well as fuzzy control chart. It highly can be applied specially in real case projects where the nature of projects is stochastically known.

ACKNOWLEDGMENTS:

The authors wish to express their acknowledgments to Iran National Science Foundation (INSF) for financial support of this research.

REFERENCES

1. Shewhart, W.A., 1931. Economic Control of Quality of Manufactured Product. D. Van Nostrand, Inc., Princeton, NJ,
2. Gulbay, M., C. Kahraman and D. Ruan, 2004. α-cut fuzzy control charts for linguistic data. International Journal of Intelligent Systems, 19: 1173-1195.
3. Laviolette, M., Jr.J.W. Seaman, J. Douglas Barrett, William H. Woodall, 1995. A probabilistic and statistical view of fuzzy methods. Technometrics, 37: 249-261.
4. Marcucci, M., 1985. Monitoring multinomial processes. Journal of Quality Technology, 17: 86-91.
5. Wang, J.H. and T. Raz, 1990. On the construction of control charts using linguistic variables. International Journal of Production Research, 28: 477-487.

6. Raz, T. and J.-H. Wang, 1990. Probabilistic and membership approaches in the construction of control charts for linguistic data. Production Planning and Control, 1:147-157.
7. Kanagawa, A., F. Tamaki and H. Ohta, 1993. Control charts for process average and variability based on linguistic data. International Journal of Production Research, 31: 913-922.
8. Taleb, H. and M. Limam, 2002. On fuzzy and probabilistic control charts. International Journal of Production Research, 40: 2849-2863.
9. Cheng, C.B., 2003. Fuzzy process control based on fuzzy regression and possibility measures. IEEE, pp: 127-131.
10. Cheng, C.B., 2005. Fuzzy process control: Construction of control charts with fuzzy numbers. Fuzzy Sets and Systems, 154: 287-303.
11. Gulbay, M. and C. Kahraman, 2007. An alternative approach to fuzzy control charts: Direct fuzzy approach. Information Sciences, 177: 1463-1480.
12. Faraz, A. and M. Bameni Moghadam, 2007. Fuzzy control chart a better alternative for Shewhart average chart. Quality and Quantity, 41: 375-385.
13. Anbari, F.T., 2003. Earned value project management method and extensions. Project Management Journal, 34 (4):12-23.
14. Vandevoorde, S. and M. Vanhoucke, 2006. A comparison of different project duration forecasting methods using earned value metrics. International Journal of Project Management, 24: 289-302.
15. Vitner, G., Sh. Rozenes and S. Spraggett, 2006. Using data envelope analysis to compare project efficiency in a multi-project environment. International Journal of Project Management, 24: 323-329.
16. Cioffi, D.F., 2006. Designing project management: A scientific notation and an improved formalism for earned value calculations. International Journal of Project Management, 24: 136-144.
17. Cioffi, D.F., 2005. A tool for managing projects: An analytic parameterization of the S-curve. International Journal of Project Management, 23: 215-222.
18. Kim, E.H., Jr.W.G. Wells and M.R. Duffey, 2003. A model for effective implementation of Earned Value Management methodology. International Journal of Project Management, 21: 375-382.
19. Moslehi, O., J. Li and S. Alkas, 2004. Web-based integrated project control system. Construction Management and Economics, 22: 35-46.
20. Al-Jibouri, S.H., 2003. Monitoring systems and their effectiveness for project cost control in construction. International Journal of Project Management, 21: 145-154.
21. Stratton, R.W., 2007. Applying Earned Schedule Analysis to EVM data for Estimating Completion Date. AACE International Transactions, EVM, 4:1-3.
22. Byrne, M.D. and M.A. Bakir, 1999. Production planning using a hybrid simulation-analytical approach. International Journal of Production Economics, 59: 305-311.
23. Kim, B. and S. Kim, 2001. Extended model for a hybrid production planning approach. International Journal of Production Economics, 73: 165-173.
24. Byrne, M.D. and M. Hossain, 2005. Production planning: An improved hybrid approach, Int. J. Production Economics, pp: 225-229.