BOSTON UNIVERSITY

IRNOP 2017

Fuzzy Earned Value Management model for uncertain and complex projects

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Introduction to Earned Value Management (EVM)

- EVM is a well-known technique to evaluate and control the project performance
- In order to measure the project health, and predict the completion cost and time, EVM relies on three key elements:
  - Planned Value (PV)
  - Earned Value (EV)
  - Actual Cost (AC)

Monetary

Exact/ Crisp value

EVM reliability

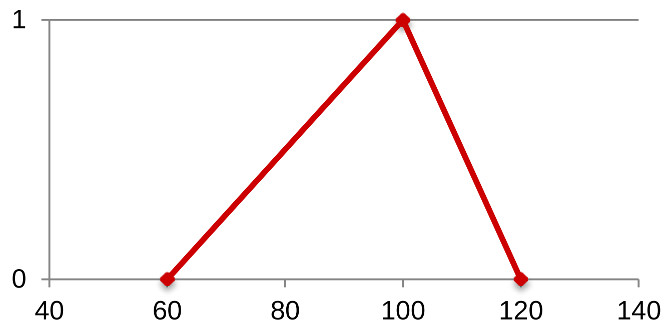
- Reliability of EVM analysis highly depends on the correctness of its elements: PV, AC and EV.
- Different methods are recommended for measuring the EV of different project activities
- Correct identification of the actual cost associated with the performed work requires to be differentiated from the cash outflow.

Fuzzy EVM

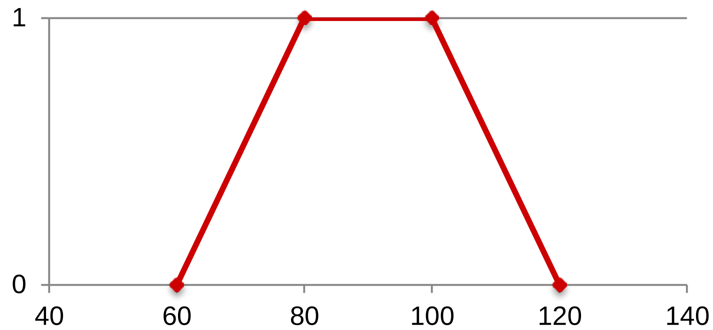
- Evaluating project performance when the key elements are uncertain.
  - Uncertainty in the value of performed work; e.g. see Naeni et al. 2011 for a method to represent EV by fuzzy numbers
  - Uncertainty in the cost spent in the performed work

Fuzzy numbers

Triangular fuzzy number



Trapezoidal fuzzy number



$\tilde{A} = [60, 100, 120]$

$\tilde{B} = [60, 80, 100, 120]$

Measure uncertain percent complete

- "What fraction/percent of the activity is completed?" → Uncertain value
- Linguistic terms can be used to evaluate the percent complete of an activity or a project.

Percent Complete

Linguistic term	Fuzzy number $(\tilde{P})$
Very low	[0, 0, 0.1, 0.2]
Low	[0.1, 0.2, 0.4, 0.5]
Almost half	[0.4, 0.5, 0.6]
High	[0.5, 0.6, 0.8, 1]
Very high	[0.8, 0.9, 1, 1]

Fuzzy Earned Value

$$\widetilde{EV}_i = \tilde{P}_i \times BAC_i$$

BAC_i: budget of activity i

$$\widetilde{EV} = \sum_{i=1}^{n} \widetilde{EV}_i$$

E.g. EV of a work package with a total budget of $1000, which is completed by almost half, is

EV = [0.4, 0.5, 0.6] x 1000 = [400, 500, 600]

Measure uncertain cost

- When the actual cost spent in an activity or work item cannot be measured precisely, linguistic terms can be used to show the level of uncertainty in the measured value.

- Linguistic terms can be used to model the "Possibility of Error" in the estimated Actual Cost; e.g. if the actual cost is "about $1000"
  - a **very high** possibility of error: [800, 1000, 1200]
  - a **very low** possibility of error: [950, 1000, 1050]

Fuzzy Actual Cost

Possibility of error in AC

Linguistic term	Fuzzy number $\tilde{\varepsilon}$
Very high	[-0.20, 0, 0.20]
High	[-0.15, 0, 0.15]
Moderate	[-0.10, 0, 0.10]
Low	[-0.05, 0, 0.05]
Very low	[-0.02, 0, 0.02]

AC_i: uncertain actual cost

$$\widetilde{AC}_i = AC_i(1 + \tilde{\varepsilon}_i)$$

$$\widetilde{AC} = \sum_{i=1}^{n} \widetilde{AC}_i$$

Fuzzy Performance Index

- $\widetilde{EV} = [EV_1,\ EV_2,\ EV_3,\ EV_4]$

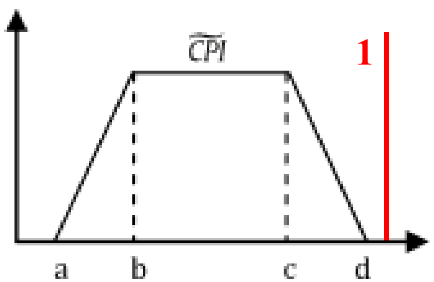
- $\widetilde{AC} = [AC_1,\ AC_2, AC_3]$

- $\widetilde{SPI} = \frac{\widetilde{EV}}{PV} = \left[\frac{EV_1}{PV}, \frac{EV_2}{PV}, \frac{EV_3}{PV}, \frac{EV_4}{PV}\right]$

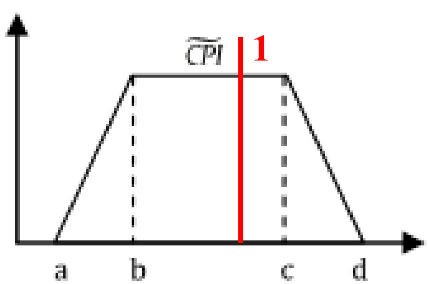
- $\widetilde{CPI} = \frac{\widetilde{EV}}{\widetilde{AC}} = \left[\frac{EV_1}{AC_3}, \frac{EV_2}{AC_2}, \frac{EV_3}{AC_2}, \frac{EV_4}{AC_1}\right]$

Interpreting a fuzzy index

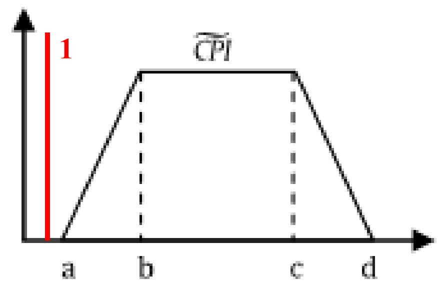
- Target value of SPI and CPI is 1.
  - Above 1: the project performs better than the plan
  - Below 1: the project performs worse than the plan



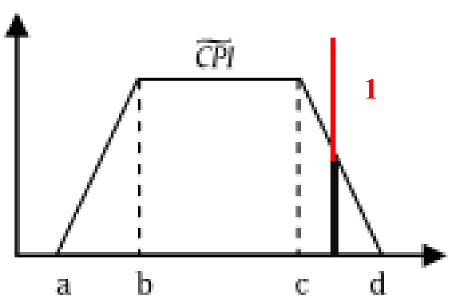
Over budget



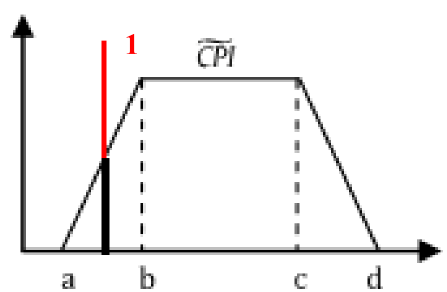
Almost on budget



Under budget



Approximately over budget



Approximately under budget

Estimating the completion

$$\widetilde{EAC} = \frac{BAC}{\widetilde{CPI}}$$

$$= \frac{BAC}{\left[\frac{EV_1}{AC_3}, \frac{EV_2}{AC_2}, \frac{EV_3}{AC_2}, \frac{EV_4}{AC_1}\right]}$$

$$= \left[\frac{BAC \times AC_1}{EV_4}, \frac{BAC \times AC_2}{EV_3}, \frac{BAC \times AC_2}{EV_2}, \frac{BAC \times AC_3}{EV_1}\right]$$

Having a fuzzy estimate at completion (time or cost), we can compute the possibility of exceeding the project budget at completion.

Example

Work item	BAC	PV	% Complete	AC	Possibility of error in AC
1	1000	700	High	~900	Moderate
2	800	300	Less than half	~400	Very high
3	1200	200	Very low	300	-
4	2000	300	20%	~400	High
Total	**5000**	**1500**		**~2000**	

Fuzzy EV

Work item	BAC	% Complete		$\widetilde{EV}$
1	1000	High	[0.7, 0.8, 0.8, 0.9]	[700, 800, 800, 900]
2	800	Less than half	[0.2, 0.3, 0.4, 0.5]	[160, 240, 320, 400]
3	1200	Very low	[0, 0, 0.1, 0.2]	[0, 0, 120, 240]
4	2000		20%	400
Total	**5000**			**[1260, 1440, 1640, 1940]**

Fuzzy AC

Work item	AC	Possibility of error	$\tilde{\varepsilon}$	$\widetilde{AC}$
1	~900	Moderate	[-0.1, 0 , 0.1]	[810, 900, 990]
2	~400	Very high	[-0.2, 0, 0.2]	[320, 400, 480]
3	300	-		300
4	~400	High	[0.15, 0 , 0.15]	[340, 400, 460]
Total	~2000			[1770, 2000, 2230]

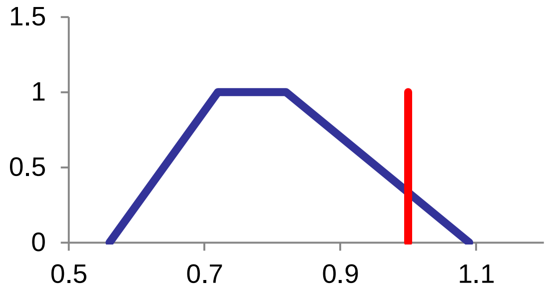
Evaluating Project Performance

BAC = 5000 , PV = 1500

$\widetilde{EV} = [1260, 1440, 1640, 1940]$

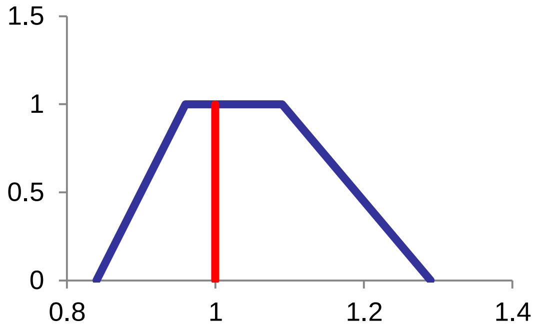
$\widetilde{AC} = [1770, 2000, 2230]$

$$\widetilde{CPI} = \frac{\widetilde{EV}}{\widetilde{AC}} = [0.56, 0.72, 0.82, 1.09]$$



Approximately over budget

$$\widetilde{SPI} = \frac{\widetilde{EV}}{PV} = [0.84, 0.96, 1.09, 1.29]$$

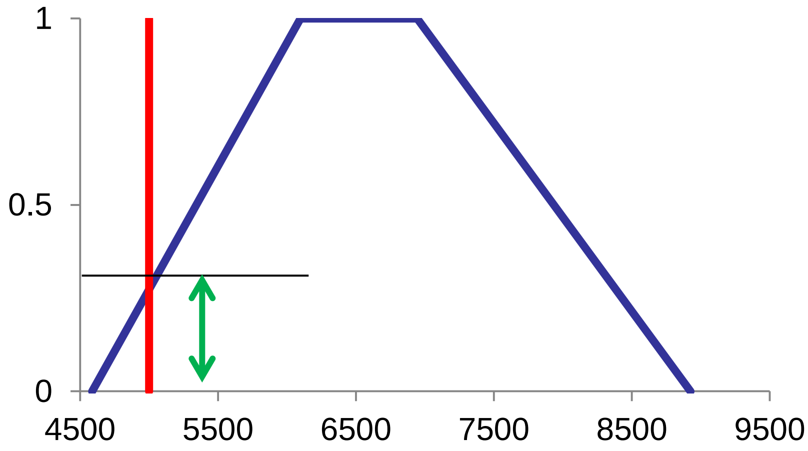


Almost on schedule

Estimate at Completion

$$\widetilde{EAC} = \frac{BAC}{\widetilde{CPI}} = [4587, 6097, 6944, 8928]$$

Possibility of meeting the budget



Without considering the uncertainty:

EV = 1500, AC = 2000, PV = 1500

CPI = 0.75 SPI = 1 EAC = 6667

Conclusions

- The new fuzzy EVM model is presented for complex projects, in which actual costs are inexact and uncertain.

- The developed model results in a more realistic and practical evaluation of the project performance.

- We are expanding the proposed model for more general cases.