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A SCENARIO BASED STOCHASTIC MULTI-OBJECTIVE MODELING FOR TIME-COST-QUALITY TRADE-OFF PROBLEM

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Abstract

Projects are often affected by several sources of uncertainties. So it is essential to have schedules that are less vulnerable to disruptions caused by these noises. In this study we investigate the stochastic time-cost-quality trade-off problem over a multi-objective approach. The model is scenario based and its basic assumption is that the probability of each scenario is available. The model is constructed and a numerical example is modeled and solved according to the proposed approach. The results show the applicability and usefulness of the method which are illustrated at the end of the paper.

Key words: *Stochastic programming, Uncertainty, Time-cost-quality trade off*

JEL code: C61

Introduction

However, in traditional project scheduling problems, only the time and cost are considered without the quality parameters, quality is the other most crucial dimension which is significantly affects a project success (Golpîra, 2012). So, balancing among these key factors has been introduced as a focus of researchers and projects managers since 1990s. El-Rayes and Kandil (2005) and Sonmez and Bettemir (2010) use a genetic algorithm to solve the time-cost-quality trade-off problem (TCTP). Tareghian and Taheri (2007) introduce electromagnetic scatter search as a solution procedure for the discrete TCTP. Huang (2008) proposes a modified ant colony algorithm; Yang (2009) suggests improved particle swarm optimization (PSO) algorithm and Zhang and Xing (2010) apply the same algorithm in fuzzy environment to deal with the problem. Shrivastava, Singh and Dubey (2012) reveal that multi colony ant algorithm is a good method to solve the problem; Shahsavari Pour, Modarres and Tavakkoli Moghadam (2012) introduce linguistic variable for the problem; Mungle et al. (2013) use a fuzzy clustering based genetic algorithm approach and Zhang (2014) studies the fuzzy time-cost-quality-environment-trade-off problem of construction project and establishes a decision making model with multiple modes under resource-constrained environment.

The existing studies generally assume complete information and deterministic environment. Nevertheless, in practice, projects are often subject to some uncertainties. Therefore, it is vital to have effective approaches to make project schedules, which are less vulnerable to disruptions caused by these noise factors. To the best our knowledge, However

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Klerides and Hadjiconstantinou (2010) address uncertainty on problem, using stochastic programming and Salmasnia, Mokhtari and Nakhai Kamal Abadi (2011) introduce the robust model to deal with TCTP; but they are not in multi-objective approach which is addressed in this study. So in this paper we suggest a new stochastic TCTP using goal programming (GP) as the well-known multi-objective decision making (MODM) method on stochastic parameters which is not addressed in the literature. To do this, in the following chapter the method and its attributes are defined, then the model is applied to an example and finally the results are revealed to show the applicability of the method.

Time-cost-quality trade-off problem under uncertainty

Stochastic programming (SP) is a well-known optimization attitude under uncertainty. SP applies probabilistic models to deal with uncertain data in terms of probability distributions. When accurate distributional information is available, stochastic programming has the advantage of incorporating this available distributional data; however, stochastic programming models are usually computationally more demanding (Hazir, Haouari and Erel, 2010).

A scenario based stochastic multi-objective modeling for TCTP is as follows:

$$Minimiz\ z = \sum_{s=1}^{s} \sum_{i=1}^{i} p_s \left(d_{si}^{+} + d_{si}^{-}\right) \quad (1)$$

S.t.: $$\sum_{p=1}^{p} x_{sp} - d_{si}^{+} + d_{si}^{-} = T_s,\ (s = 1, \ldots s),\ (i = 1, \ldots i) \quad (2)$$

$$\sum_{p=1}^{p} c_{sp} x_{sp} - d_{si}^{+} + d_{si}^{-} = TC_s,\ (s = 1, \ldots s),\ (i = 1, \ldots i) \quad (3)$$

$$\sum_{p=1}^{p} l_{sp} x_{sp} - d_{si}^{+} + d_{si}^{-} = Q_s,\ (s = 1, \ldots s),\ (i = 1, \ldots i) \quad (4)$$

$$\sum_{p=1}^{p} a_{sp} x_{sp} \le LMC_s,\ (s = 1, \ldots s),\ (i = 1, \ldots i) \quad (5)$$

$$1 \le x_{sp}, d_{si}^{+}, d_{si}^{-} \ge 0,\ (i = 1, \ldots i),\ (p = 1, \ldots p),\ (s = 1, \ldots s) \quad (6)$$

Where *s* is the scenario number, *i* is the constraint number and *p* is the project phase number. p_s is the probability of the scenario *s* and d_{si}^{+}, d_{si}^{-} are respectively the under-achievement and over-achievement of the i^{th} goal for the s^{th} scenario. x_{sp} is duration of phase *p* over scenario *s*. T_s is total time of the project over scenario *s*; TC_s is total cost of the project over scenario *s*; Q_s is total quality achieved over scenario *s* and LMC_s is total labor and material cost for the project over scenario *s*. a_{sp} labor and material cost coefficient for phase *p* over scenario *s* of the project.

Simulation and results

To illustrate usefulness and practicability of the proposed approach, an empirical study considering a real project consisting three phases- planning, scheduling and controlling- is given as a sample of construction projects. The data for this study are collected in winter 2013 in Kurdistan. The data of the problem is illustrated in Table 1 and Table 2. Besides, Some assumptions are considered in this problem: (1) there are three scenarios extracting from the real world which have the predefined probabilities as shown in Table 1; (2) each scenario has the predefined unique data as shown in Table 1 and Table 2; (3) cost of quality for each scenario is defined by unique fixed ratio of the total cost of the project which is shown in Table 1.

Table 1

Problem data of each scenario over each scenario

Scenario	Probability of Sc.	Phases	Phases name	Human recourses monthly cost	Other monthly costs	Monthly cost of quality
1	0.40	1	Plan	16	20	30
		2	Scheduling	18	26	5
		3	Control	25	30	20
2	0.35	1	Plan	10	20	24
		2	Scheduling	12	18	4
		3	Control	22	25	16
3	0.25	1	Plan	20	18	22.5
		2	Scheduling	16	20	3.75
		3	Control	30	40	15

Table 2

Problem data of the total project

Scenario	Total cost of human recourses and material	Total cost of project	Time table of the project	Total cost of quality of the project
1	800	1000	36	3.5
2	500	800	30	3
3	400	750	24	4

According to data from Table 1 and Table 2, considering the proposed method predefined by Eq. (1) to Eq. (6), the problem is modeled as follows:

$$Min\ Z = 0.4(d_{11}^{+} + d_{11}^{-} + d_{12}^{+} + d_{12}^{-} + d_{13}^{+} + d_{13}^{-}) + 0.35(d_{21}^{+} + d_{21}^{-} + d_{22}^{+} + d_{22}^{-} + d_{23}^{+} + d_{23}^{-}) + 0.25(d_{31}^{+} + d_{31}^{-} + d_{32}^{+} + d_{32}^{-} + d_{33}^{+} + d_{33}^{-})$$

$$\begin{aligned}
s.t.:\quad & x_{11} + x_{12} + x_{13} + d_{11}^{-} - d_{11}^{+} = 36\\
& 20x_{11} + 26x_{12} + 30x_{13} + d_{12}^{-} - d_{12}^{+} = 1000\\
& 0.03x_{11} + 0.2x_{12} + 0.05x_{13} + d_{13}^{-} - d_{13}^{+} = 3.5\\
& 16x_{11} + 18x_{12} + 25x_{13} \le 800\\
& x_{21} + x_{22} + x_{23} + d_{21}^{-} - d_{21}^{+} = 30\\
& 20x_{21} + 18x_{22} + 25x_{23} + d_{22}^{-} - d_{22}^{+} = 800\\
& 0.04x_{21} + 0.25x_{22} + 0.06x_{23} + d_{23}^{-} - d_{23}^{+} = 3\\
& 10x_{21} + 12x_{22} + 22x_{23} \le 500\\
& x_{31} + x_{32} + x_{33} + d_{31}^{-} - d_{31}^{+} = 24\\
& 18x_{31} + 20x_{32} + 40x_{33} + d_{32}^{-} - d_{32}^{+} = 750\\
& 0.04x_{31} + 0.26x_{32} + 0.06x_{33} + d_{33}^{-} - d_{33}^{+} = 4\\
& 20x_{31} + 16x_{32} + 30x_{33} \le 400
\end{aligned}$$

$$x_{11}, x_{12}, x_{13}, x_{21}, x_{22}, x_{23}, x_{31}, x_{32}, x_{33} \ge 1,$$
$$d_{11}^{+}, d_{11}^{-}, d_{12}^{+}, d_{12}^{-}, d_{13}^{+}, d_{13}^{-}, d_{21}^{+}, d_{21}^{-}, d_{22}^{+}, d_{22}^{-}, d_{23}^{+}, d_{23}^{-}, d_{31}^{+}, d_{31}^{-}, d_{32}^{+}, d_{32}^{-}, d_{33}^{+}, d_{33}^{-} \ge 0$$

The problem is a linear stochastic goal programming which is simply solvable by Lingo software. The results are shown in Table 3.

Table 3

Solution data of the empirical example

Scenario	Variable /Underachievement of goal	Value	Variable /Overachievement of goal	Value	Decision Variable	Value
1	d_{11}^{-}	0	d_{11}^{+}	0	X_{11}	3.29
	d_{12}^{-}	0	d_{12}^{+}	0	X_{12}	11.77
	d_{13}^{-}	0	d_{13}^{+}	0	X_{13}	20.93
2	d_{21}^{-}	0	d_{21}^{+}	7.54	X_{21}	26.33
	d_{22}^{-}	0	d_{22}^{+}	0	X_{22}	1
	d_{23}^{-}	1.08	d_{23}^{+}	0	X_{23}	10.21
3	d_{31}^{-}	9.86	d_{31}^{+}	0	X_{31}	1
	d_{32}^{-}	226.66	d_{32}^{+}	0	X_{32}	1
	d_{33}^{-}	3.29	d_{33}^{+}	0	X_{33}	12.13

As you one can see in Table 3, if manager has no propensity to any tradeoff between time, cost and quality, he should plan the project using scenario 1. In other words, if the manager selects the scenario 1, the tradeoff is not needed and the project may be finished exactly. But if the scenario 2 is taking place, a manager may expense 7.54 time units (21%) rather than the scheduled time of the project, in order to achieve 36% fewer cost of quality. If scenario 3 is taking place, because the lower bound of the all x_{ij}s, the project may finished at 9.86 time units (41%) rather than the scheduled time of the project and 226.66 units of cost (30%) rather than the basic scheduled total cost in order to achieve 3.29 units of cost of quality (82%) fewer than what is been scheduled.

Conclusion

In this paper we consider the time-cost-quality trade-off problem in the field of project management under stochastic manner to handle the uncertainty of the real world projects environments. To deal with this uncertainty, we adopt the scenario approach. As one can see, the model exactly helps the decision maker to have a better solution if each scenario is happened and in this decision making helps him/her to make better optimal tradeoff between all the critical factors of project. In addition to handling uncertainty, the variety of scenarios that can be considered, numerous constraints that may be indicated in the model and its simplicity and solvability are making the model more flexible and practical in real worlds.

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