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Time, Cost and Quality Trade-off Analysis in Construction of Projects

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Abstract

The completion time and nonrenewable resources are traditionally considered for construction of project. When renewable resources, quality and some criteria considered for the project, the risk related to criteria has to be taken into account. Thus project planning problem can be defined as multicriteria decision problem under risk. In this paper, a project scheduling problem including time, cost, quality trade offs is analyzed. First, evaluations of projects with respect to the criteria are generated. Next, these evaluations are compared with respect to the criteria. Finally, the interactive technique is used for the selection of the most desirable resource allocation. A numerical example is presented to illustrate the applicability of the new technique in construction of projects.

Keywords: Time-cost-quality trade off, project planning, multicriteria decision problem, stochastic dominane

1. Introduction

In the time, cost, quality trade off analysis for construction project, the objective is to construct project using computer simulation and interactive procedure. The traditional discrete time cost trade off problem (DTCTP) with renewable and nonrenewable resources analyzed by Wulang Peng, Hong Yu [1]. Time, cost, quality considerations are considered for project evaluation by Rong Xian [2]. Babu and Suresh [3] proposed a new method to study the trade off among time, cost, and quality.

In practice, however, one of the critical measures of project success is the quality of its performance that may be affected by attempt to crash the completion time with additional budget [4,5]. We have to deal with criteria conflicts when two objectives time compression and cost cutting are subjects to be reached. This kind of problem, referred to as time-cost trade off was recognized by Fulkerson [6] and Kelly [7].

Different heuristical approaches were presented by Siemans [8] and Moselhi and Deb [9]. Metaheuristics such as genetic algorithm were exploited in solving this problem by Feng et al [10] and Chua et al [11]. Multicriteria techniques are widely used in project selection problems. Nowak [12] proposed a technique based on simulation model, stochastic dominance rules and a multicriteria aggregation procedure. In the paper [13] a new discrete resource quality constrained time cost trade off problem, which involves renewable resources, non renewable resources and quality constraints. This paper proposes a new approach for a project scheduling problem including time, cost, and quality trade offs. We assume that various resource allocations (renewable and non renewable resources) can be considered.

2. Problem formulation

In project planning problem, various resources can be used to complete project activities. We face a discrete decision making problem, in which the decision projects are defined by the resource allocations. The completion time depends on the resources allocated to the activity. We assume that for each activity and for each project resource allocation, the relations between time, cost and quality are recognized. For example, if we know the wage per hour paid to a worker and the completion time, we are able to calculate cost of the activity and project cost. Similarly, the cost of other resources can be estimated. As the activity times are uncertain, the project completion time and project costs are uncertain as well.

The decision situation considered in this paper may be conceived as a problem (A,X,E) where A is a finite set of projects a_i, i=1,2,…,m, X is a finite set of criteria X_k, k=1,2…,n and E is the set of evaluations of projects with respect to criteria. In this case, the decision projects are evaluated with respect to three criteria: the project completion time, total cost and quality. Performances of each project with respect to criteria are evaluated by the distributions functions. Stochastic Dominance (SD) rules are used for comparing distributional evaluations. Huangetal [15] show that if the additive independence condition is verified is the necessary condition for multi-attribute stochastic dominance (MSD). MSD is the verification of stochastic dominance with respect to each criterion. In practice, MSD rule is very rarely verified. Zaras and Martel [16] suggest weakening the unanimity condition and accepting a majority criteria condition. They propose MSD for a reduced number of criteria. The procedure consists of two steps. Firstly, the SD relations are verified for each pair of projects with respect to all criteria. Secondly the multi attribute aggregation is realized the ELECTREI methodology is used to obtain the final ranking of projects. The solution of multiple criteria decision making problem is possible if the decision maker is able to provide information his preferences with respect to the set of objectives and consideration. Procedures listed above assume that the preference information is collected prior to calculating the final solution .The analysis is therefore based on an priori bases. In many situations, how ever, the decision maker is unable or unwilling to provide all required information at the same time.

A methodology the interactive approach is very useful in such cases. This technique assumes that the decision maker is able to provide the preference information with respect to a given solution or a given set of solutions. Two main advantages are usually mentioned for employing interactive techniques. Firstly, such methods need much less information on the preferences of the decision maker. Secondly, since the decision maker is closely involved in all phases of the problem solving process, he put much reliance in the generated solution, and, as a result, the final solution has a better chance of being implemented. Numerous interactive techniques have been proposed in recent years.

Most of them are applicable in circumstances of certainty, although the methods devised for the case of risk are also proposed. The INSDECM technique which was presented in Nowak[12], combines the interactive approach and the risk analysis based on the stochastic dominance and mean -risk analysis. Tomasz Blaszczyk, Maciejnowak [17] analyzed the time cost network trade off analysis in construction project using computer simulation and interactive procedure. In this work we use this method for solving the project planning problem.

3.Methodology

The procedure we propose here consists of three steps. First, evaluations of projects with respect to the criteria are generated. Next, these evaluations are compared with respect to the criteria. Finally, the interactive technique is used for the selection of the most desirable resource allocation. The steps required to perform the analysis are described below.

Step1: The generation of project evaluations.

Our approach uses the evaluations of projects with respect to criteria. One of the most important point is identifying appropriate probability distribution for the input data. Usually, it requires analyzing the data and fitting these data to distributions. Some times, however, such data are not available and an appropriate distribution has to be selected according to the decision maker's or expert's judgment.

Step2: Comparing the projects with respect to the criteria.

Once the project evaluations are obtained, the relations between the projects with respect to the criteria can be analyzed. Two methods are usually used for comparing uncertain outcomes: mean risk analysis and stochastic dominance. The former is based on two criteria: one measuring expected outcome another representing variability of outcomes. In the stochastic dominance approach random variables are compared by pointwise comparison of their distribution functions. In this paper both techniques are used. While the stochastic dominance is employed for constructing rankings of projects with respect to each criterion, mean risk technique is used when a final solution is chosen.

Let $P_{ik}(x)$ and $P_{jk}(x)$ be continuous cumulative functions that represents the projects a_i and a_j respectively over criterion X_k :

$P_{ik}(x) =$ Probability of $\{X_{ik} \le x\}$,

$P_{jk}(x) =$ Probability of $\{X_{jk} \le x\}$.

Stochastic Dominance(SD) 1 :

X_{ik} dominates X_{jk} if and only if $P_{ik}(x) \neq P_{jk}(x)$ and $P_{ik}(x) - P_{jk}(x) \le 0$ for $x \in R$.

Stochastic Dominance(SD) 2 :

X_{ik} dominates X_{jk} if and only if $P_{ik}(x) \neq P_{jk}(x)$ and $\int_{-\infty}^{x} [P_{ik}(y) - P_{jk}(y)]\, dy \le 0$

for $x \in R$.

Step3. Selecting final solution

As soon as the relations between the projects with respect to each criterion are identified, we are able to select the efficient projects. We assume that project a_i is efficient if and only if for no other project a_i the following condition is fulfilled:

For all k=1,…, n , $X_{jk} \blacktriangleright_{SD} X_{ik}$, where $\blacktriangleright_{SD}$ stands for stochastic dominance relation. Thus we assume that project a_i is efficient if there is no other project that dominates a_i according to stochastic dominance rules with respect to all criteria. The set of efficient projects A can be identified by pairwise comparisons.

4. Mathematical Notation & Linear programming models

x_{ijk} = 1 if activity (i,j) is executed in mode k

= 0 otherwise

m= number of modes

t_{ijk} = duration of activity (i,j) in mode k

r_{ijk} = the amount of renewable resource r

P_r = price of the renewable resource r

c_{ijk} = cost of the activity (i,j) = $t_{ijk} \times r_{ijk} \times P_r$ + the cost of non renewable resources

q_{ijk} = quality of activity (i,j) in mode k

N_i = { E_i , E_i+1, …, L_i}, where E_i is the earliest time of occurrence for event i and L_i is

the latest time of occurrence for event i.

y_{iu} = 1 if event i occurs in time u

= 0 otherwise

M_T = maximum time to complete the project

B_{max} = maximum available budget

l_{ij} = lower bound for quality of activity (i,j)

Three mathematical models using 0-1 integer linear programming are

(i) Max $z_1 = \left(\prod_{(i,j)\in A} \left(\sum_{k=1}^{m} q_{ijk} x_{ijk} \right) \right)^{\frac{1}{|A|}}$,

Subject to constraints

$$\sum_{k=1}^{m} x_{ijk} = 1$$

$$\sum_{u\in N_j} u y_{ju} - \sum_{w\in N_i} w y_{iw} \geq \sum_{k=1}^{m} t_{ijk} x_{ijk}$$

$$\sum_{u\in N_n} u y_{nu} \leq M_T ,$$

$$\sum_{(i,j)\in A}\sum_{k=1}^{m} c_{ijk}x_{ijk} \le B_{\max},,$$

$$\sum_{k=1}^{m} q_{ijk}x_{ijk} \ge l_{ij}$$

where (i,j) is an activity , x_{ijk} = 0 or 1 for each activity(i,j) executed in each mode k and y_{iu}= 0 or 1 for each event i and for each u $\in N_i$,

(ii) Min $Z_2 = \sum_{k=1}^{m} c_{ijk}x_{ijk}$

Subject to

$$\sum_{k=1}^{m} x_{ijk} = 1$$

$$\sum_{u\in N_j} uy_{ju} - \sum_{w\in N_i} wy_{iw} \ge \sum_{k=1}^{m} t_{ijk}x_{ijk}$$

$$\sum_{u\in N_n} uy_{nu} \le M_T,$$

$$\sum_{k=1}^{m} q_{ijk}x_{ijk} \ge l_{ij}$$

where (i,j) is an activity , x_{ijk} = 0 or 1 for each activity(i,j) executed in each mode k and

y_{iu}= 0 or 1 for each event i and for each u $\in N_i$,

(iii) Min $z_3 = \sum_{u\in N_n} uy_{nu}$

Subject to

$$\sum_{k=1}^{m} x_{ijk} = 1$$

$$\sum_{u\in N_j} uy_{ju} - \sum_{w\in N_i} wy_{iw} \ge \sum_{k=1}^{m} t_{ijk}x_{ijk}$$

$$\sum_{(i,j)\in A}\sum_{k=1}^{m} c_{ijk}x_{ijk} \le B_{\max},$$

$$\sum_{k=1}^{m} q_{ijk}x_{ijk} \ge l_{ij}$$

where (i,j) is an activity , x_{ijk} = 0 or 1 for each activity(i,j) executed in each mode k and y_{iu}= 0 or 1 for each event i and for each u $\in N_i$.

5. Numerical example

Table I presents the description of the project and Fig.1. represents the project network. Earliest times, Latest times, and total float of each activity in the network are calculated and presented in Table II. Critical path of the project is 1-3-4-6-7-8 and project duration is 96 days.Total cost of the project is calculated by considering renewable and nonrenewable resources. Similarly we consider several projects and calculated cost, time, quality for the projects using linear programming models in Section 4 and are presented in Table III.

Table I : Project Description

Activity	Description	Activity	Description
1-2	Plan approval	4-5	Raising walls from foundation to windows level
1-3	Site preparation		
1-4	Laying foundation	4-6	making doors , windows and fitting them
2-5	Sanitary work		
3-4	Raising walls from foundation to windows level	5-7	roofing
		5-8	electrical wiring
		6-7	plastering
3-6	Interior arrangements	7-8	white washing

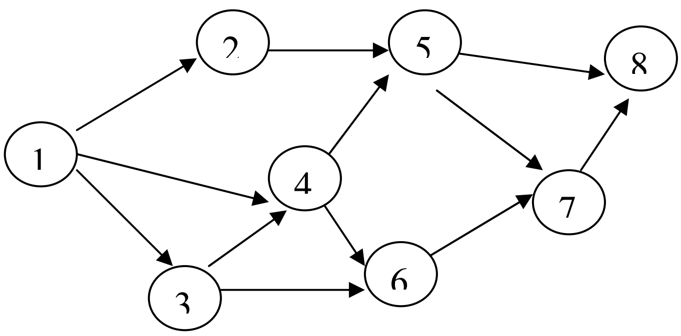

Fig.1 Project Network

Table II : Network times

Activity	Duration (days)	Earliest		Latest		Total float
		Start	Finish	Start	finish	
1-2	18	0	18	36	54	36
1-3	20	0	20	0	20	0
1-4	26	0	26	11	37	11
2-5	21	18	39	54	75	36
3-4	17	20	37	20	37	0
3-6	22	20	42	33	55	13
4-5	18	37	55	57	75	20
4-6	18	37	55	37	55	0
5-7	16	55	71	67	83	12
5-8	21	55	76	75	96	20
6-7	28	55	83	55	83	0
7-8	13	83	96	83	96	0

Table III The set of projects with time, cost and quality

Project	Time (days)	Cost (Rupees in thousands) (Renewable &Nonrenewable)	Quality	Project	Time (days)	Cost (Rupees in thousands) (Renewable &Nonrenewable)	Quality
P_1	96	3758	0.97	P_{10}	110	3680	0.95
P_2	100	3692	0.98	P_{11}	70	4200	0.83
P_3	83	4024	0.90	P_{12}	66	4319	0.82
P_4	91	3835	0.95	P_{13}	63	4390	0.81
P_5	98	4000	0.94	P_{14}	79	4526	0.90
P_6	88	3944	0.94	P_{15}	80	4327	0.92
P_7	74	4148	0.86	P_{16}	76	4592	0.88
P_8	78	4080	0.89	P_{17}	87	3889	0.92
P_9	84	3999	0.91	P_{18}	105	3669	0.94

We generate the set of efficient projects by comparing evaluations of projects employing stochastic dominance rules. For example project P_5 is dominated by P_{17}

Since $X_{(5,1)} > X_{(17,1)}, X_{(5,2)} > X_{(17,2)},$and $X_{(5,3)} > X_{(17,3)}$
Similarly, project P_{10} is dominated by P_{18} and project P_{15} is dominated by P_{12}
The efficient set consist 15 projects:
$A= \{ P_1, P_2 ,P_3, P_4 , P_6, P_7, P_8, P_9, P_{11}, P_{12}, P_{13}, P_{14}, P_{16}, P_{17} P_{18}\}$
Criterion –X_1: Time will not exceed 90 days
X_2: Cost will not exceed Rupees('000) 4200
X_3: Quality will not less than 0.92.
The set of projects satisfies the criterion X_1 is
$A_1= \{P_3, P_6, P_7, P_8, P_9, P_{11}, P_{12}, P_{13}, P_{14}, P_{16}, P_{17} \}$
The set of projects satisfies the criterion X_2 from A_1 is
$A_2= \{P_3, P_6, P_7, P_8, P_9, P_{11}, P_{17}\}$
The set of projects satisfies the criterion X_3 from A_2 is $A_3= \{P_{16}, P_{17} \}$
Projects satisfying restrictions specified by decision maker are presented in Table IV.

Table IV Data presented to the decision maker

Project	**Time (days)**	**Cost (Renewable &Nonrenewable)**	**Quality**
P_6	88	3944	0.94
P_{17}	87	3889	0.92

The decision maker selects project P_6 as the final solution by giving preference for quality constraint by using Table IV.

6. Conclusion

In this paper, the discrete time, cost, quality trade –off problem has been considered. As the finite number of project resource allocations has been considered, we have faced the discrete decision- making problem under risk. We have proposed a new method for such a problem in construction field. The applicability of the procedure presented here is not limited to the construction project planning problems. It may be useful for various types of problems in which uncertain out comes are compared. It can be also applied. For example, in inventory models, evaluation of investment projects, production process control, and many others.

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