TIME-COST-QUALITY-RISK TRADE-OFF IN ENGINEERING PROJECTS

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Abstract- In project management, the fundamental project concepts of Time, Cost, Quality and Risk are conflicting terms which should be appropriately assigned to project activities to achieve the desired objectives of project stakeholders. In this study an optimization model was developed for Time-Cost-Quality-Risk-Trade-offin projects. The algorithm was implemented in the MATLAB software using multiobjective genetic algorithm and applied to a sample 18-activity project.Pareto optimal solutions were generated from which the decision maker can choose based on his preferences.

Keywords- Time Cost, Quality, Risk And Optimization.

I. INTRODUCTION

The time, cost, quality and risks are very important objectives crucial to the successful completion of projects. The Time-Cost Trade-off problem (TCTP), has been thoroughly investigated by several authors (Feng et al. 1997; Leu et al. 2001) and proved by De et al. (1997) to be strongly NP-hard. Babu & Suresh, (1996) suggested that crashing a project might affect its quality. Other researchers have since corroborated their work and developed various TCQTP (Ghodsi, et al. 2009; Zhang& Xing,2010).

A survey of existing literature reveals that a number of optimization models have been researched including Time-Cost Trade-off Problem (TCTP), Time-Cost-Quality trade-off Problem (TCQTP) (Zhang & Xing, 2010; Salmasnia et al. 2011),Time-Cost-Risk trade-off Problem (TCRTP) (Nwaneri, &Anyaeche, 2014;Lakshminarayanan, et al. 2011) and Time-Cost Environment trade-off Problem(TCETP)(Xu et al. 2012). While the TCTP and TCQTP have been well research, the TCETP and TCRTP have been sparsely investigated. In addition, the optimization models comprise mostly two or three objectives. This study investigates the Time-Cost-Quality-Risk trade-off Problem (TCQRTP).

The concept of trading off risk has been sparsely combined with any of the other objectives (Lakshminarayanan, 2011). Khozein, et al. (2012)investigated the optimization of TCQRT and introduced the survival pyramid. However, no quantitative methods were used to address the problem. The need to develop a stochastic TCQRT model with the ability to maximize quality while minimizing the duration, cost and risk using limited resources cannot be over-emphasized. To the best of our knowledge, this problem is yet to be addressed in literature. The problem has a greater degree of complexity, than the TCTP which is NP-hard (De et al. 1997).

II. MATERIALS AND METHODS

2.1 Problem Description and Mathematical Model

The problem is to develop a model for the optimization of TCQRTP to ensure that the total Time T, Cost C, and Risk R are minimized while the Quality Q is maximized.Each activity is associated with a certain amount of quality q_i, and subjected to a specific amount of risk r_{ij}, having an impact and probability of occurrence based on the following assumptions:

1. The duration of an activity is stochastic.
2. The precedence network is based on the Finish-to-Start (FS) activity relationship.
3. Crashing a project is characterized by a certain level of risk which is proportional to the direct cost of the project.
4. The PERT is assumed to be continuous uniformly distributed

A mathematical formulation of the problem is hereby presented.

2.1.1 Notation and Variables

i Index of activities
j Index of nodes in project network
$t_{ij}(x_{ij})$ Expected duration of activity when resource $r_{ij}$is assigned to A_{ij}
a Optimistic time estimate
b pessimistic time estimate
m most likely time estimate
$C_{ij}(x_{ij})$ The normal Cost of assigning resource r_{ij} to activity A_{ij}
q_{ij} Quality of performing activity I in mode j
q_{ij}' Quality of an activity that has been crashed using mode j
w_{ij} weight of quality indicator of activity i in mode j
R_{ij} Total value of risk for project activities
r_{ij} Risk of performing activity i in mode j
r_{ij}' Risk of crashing activity i in mode j
P_{jn} Probability of risk n occurrence for activity j.
I_{jn} Impact of risk n occurrence for activity

2.1.2. Objective Functions:

Equations (1) – (4) are the objective functions. Equations (1),(2) and (4) minimize the time, cost and risk respectively, while equation (3) maximizes the quality. The constraints are represented by equations (5) – (8).Equation (5) represents the precedence constraint. Equation (6) ensures normal and crash times represent the upper and lower limits of project duration which should not be violated. Equation (7) represents the start time should always be zero. Equation (8) represents the non-negativity constraint.

$$\begin{cases} \text{Min } f_1 = \sum_{i=1}^{n} t_{ij}(x_{ij}) \quad (1) \\ \text{Min } f_2 = \sum_{i=1}^{n} C_{ij}(x_{ij}) + \sum_{i-1}^{n} C_f \quad (2) \\ \text{Max } f_3 = \sum_{i=1}^{n} q(x_{ij}) \quad (3) \\ \text{Min } f_4 = \sum_{i=1}^{n} R_{ij} \quad (4) \\ \text{S.t} \begin{cases} S_j - S_i \geq t_{ij}(x_{ij}) \quad (5) \\ l_{ij} \leq x_{ij} \leq U_{ij} \quad (6) \\ x_1 = 0 \quad (7) \\ C_R \geq 0, \quad t_{ij}(x_{ij}) \geq 0, \quad x_i \geq 0 \quad (8) \end{cases} \end{cases}$$

2.2Solution Procedure

The model was implemented using multiobjective genetic algorithm (MOGA) on MATLAB software (R2009a) version. The TCQRTP is an NP-hard Multi-Objective Optimization (MOOP) and there are no known optimal solutions for large scale problems. MOGA can provide suitable Pareto optimal solutions for the decision maker to choose the solution based on predetermined preferences. M-files were created for the fitness function and MOGA function GAMULTIOBJ respectively. The fitness function was used in the selection process to determine the surviving chromosomes for the next generation.

Table 1: Parameter Settings for MOGA

Parameter	Values
Population	500
Generation	1000
Crossover	Single point crossover
Crossover Fraction	0.7
Mutation	Adaptable Feasible
Pareto fraction	0.35
Distance Measurement Function	Distance crowding

2.3 Numerical Example for 18-Activity Project

The model was applied to a project data of 18 activities first introduced by Feng et al.(1997) and applied by many other researchers in previous studies (El-Rayes&Kandil, 2005; Hegazy, 1999;Ng & Zhang, 2008).We modified the data to include parameters for quality and risk.The indirect cost for the project was given at the rate of $1,000 per day. The project data is presented in table 1 below. The multiobjective genetic algorithm was run with the parameters presented on table 2.

III. RESULTS

The optimization results are presented on table 2.

Table 2: Results for TCQRTP For 18 Activity Project Using continuous Uniform Distribution

Time(Days)	Cost	Quality (%)	Risk	Time	Cost	Quality	Risk	Time	Cost	Quality	Risk
93.99	233326.67	96.30	0.437	120.00	199706.35	96.69	0.526	131.00	235090.03	95.32	0.688
96.77	232883.10	96.32	0.444	135.99	186781.09	96.86	0.576	131.00	234890.02	95.33	0.689
104.68	226068.76	96.45	0.468	125.00	198748.58	96.78	0.539	145.99	228201.86	95.46	0.747
103.17	226839.21	96.43	0.463	129.53	190918.74	96.81	0.558	142.00	228463.61	95.45	0.741
97.03	230898.51	96.33	0.446	133.24	189084.65	96.82	0.558	133.84	233002.37	95.38	0.699
103.00	225627.97	96.45	0.468	130.25	191995.28	96.85	0.562	134.14	233526.47	95.34	0.694
104.38	225820.58	96.46	0.469	135.99	186781.09	96.86	0.576	132.73	233264.52	95.35	0.695
95.82	231609.34	96.31	0.441	123.25	194211.06	96.78	0.549	134.28	231517.62	95.36	0.698
101.36	227492.26	96.41	0.461	130.00	188608.50	96.85	0.565	143.75	229720.40	95.44	0.727
103.51	225752.25	96.43	0.465	120.75	199615.96	96.70	0.536	142.71	229845.00	95.44	0.725
103.89	225255.29	96.45	0.470	132.74	189145.07	96.82	0.558	133.03	233942.63	95.34	0.693
105.26	225342.42	96.46	0.469	122.00	199576.35	96.69	0.530	133.08	234719.61	95.34	0.692
98.03	227906.59	96.34	0.452	131.74	191316.53	96.79	0.550	144.25	228463.08	95.45	0.746
104.93	226792.91	96.44	0.464	127.69	192198.55	96.81	0.549	142.47	228850.98	95.44	0.723
94.00	233326.69	96.30	0.437	130.49	196222.88	96.80	0.548	143.41	228809.85	95.43	0.715
95.20	231071.14	96.31	0.443	134.24	189930.47	96.85	0.571	135.86	230734.55	95.40	0.704
101.02	229799.01	96.37	0.454	125.75	198086.00	96.80	0.547	131.00	235090.03	95.32	0.688
101.62	231115.76	96.43	0.462	120.00	199706.35	96.69	0.527	143.75	229753.73	95.44	0.727
94.48	232617.16	96.31	0.441	130.31	189589.28	96.81	0.556	143.86	228732.36	95.44	0.717
99.04	230097.23	96.39	0.456	121.53	199021.15	96.77	0.534	132.00	234870.02	95.32	0.688

The proposed model in this study has addressed the optimization of TCQRTP with the aim of minimizing project duration, at the minimum cost and risk as well as at the best quality possible. Thus addressing all four objectives. Increasing the amount of resources allocated to the project reduces the time for project completion while the quality may improve or reduce depending on the amount of resources allocated to the project. To ensure that the quality is not reduced further addition of resources should not reduce the project duration. This accounts for cost of quality improvement. Project managers should ensure that project crashing is moderately done to minimize the cost of quality improvement. The model is therefore efficient in predicting the time, cost,quality and risk trade-off of the project. The study also revealed that each execution method is associated with a certain level of risk. The risk appetite and preference of the decision maker will to a large extent determine the execution mode for each project. The quality needs of the project will determine the execution method to the used. Based on the results obtained the project manager is free to choose any preferred result. If preference is given to the timely completion of the project then the option with the minimum project duration is chosen. Also, if the preference is given to the minimum costs and risks of the project, the options with the minimum costs and risks are chosen. On the contrary the decision maker may choose the option with the maximum quality value when preference is given to the completion of the project at the best quality level.

CONCLUSIONS

In this study, an optimization model for the TCQRTP in projects was developed and applied to test problems. Uncertainty in project duration was addressed by applying the continuous uniform distribution. The problem is a MOOP, which was solved using MOGA to obtain pareto optimal solutions for the four objectives of the MOOP in a single simulation run. The algorithm was developed in MATLAB and applied to test problems of 18-activity projects. Pareto optimal solutions were obtainedat good processing times. It is left for the decision maker to choose appropriate values based on his preferences for any of the objectives.

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