Time-Cost Trade off to Compensate Delay of Project Using Genetic Algorithm and Linear Programming

Hamed Naseri and Mohammad Ali Etebari Ghasbeh

***Abstract*—In projects, specific times are considered for controlling, monitoring, and measuring the development. In monitoring day, the delay may exist. Contractor should pay definite money for delay punishment at the end of project. Also contractor can hire new workers and can use extra equipment to reduce the duration time of project. Time-cost trade off analysis is considered to make balance between paying money for increasing resources and paying money for delay punishment to minimize the cost. Genetic algorithm and Linear programming are used to show the efficiency of time-cost trade off analysis in a case study. Both algorithms provide suitable solutions. Nevertheless, the Linear programming solution is better than that of Genetic algorithm.**

***Index Terms*—Cost of delay punishment, Genetic Algorithm (GA), Linear Programming (LP), optimization, Time-Cost Trade off Problem (TCTP).**

I. Introduction

Time and cost are the most effective criteria to measure the feasibility of projects. So before starting projects, construction decision makers investigate on time and cost of projects. They try to minimize the cost and time, and trade-off between them.

Time-cost trade-off analysis is one of the most important aspects of construction project planning and control. In general, there are trade-offs between time and cost to complete each activity of a project. The usual relationship is that the less expensive the resources used, the longer it takes to complete an activity. For example, using more productive equipment or hiring more workers may save time but would be more expensive [1]. Although minimizing the construction cost following a pre-planned schedule is important for both the owner and contractors in the course of construction, it is more important to select a construction duration, which will bring the highest economic return on the total investment the project, when preparing the project schedule and budget. Thus, the relationship between the time and cost of a project has drawn more and more research attention in recent decades [2].

After starting projects, there are several issues such as unpredictable climate changing, traditional type of contract, inadequate contractor experience, finance and payment, labor productivity, slow decision making which may cause delay in projects [3]. There are definite times for controlling, monitoring, and measuring the development of projects. After each controlling, the delay and remaining time to finish the project are computed. If delay is existed in project, contractor would compensate this delay or he would pay definite amount of money for each day which is called delay punishment. Contractor can hire more workers and use more productive equipment to compensate the delay. However in some situations, paying delay punishment is more economical than hiring new works and new equipment. So, Time-cost trade off analysis can offer apposite solution for this problem.

II. Literature Review

Time-cost trade off analysis is one of the most important aspects of construction project planning and control. The studies were carried to trade-off between cost and time.

Hua Ke [4] conducted a research about uncertain random time-cost trade-off problem. In his paper, combined with uncertainty theory and dependent-chance programming, an uncertain random time-cost trade-off model is built. A crisp equivalent model is also given for some special case. Besides, uncertain random simulation and genetic algorithm are integrated for solving the proposed model.

Shih-Pin Chen [5] investigated on analysis of project networks by time cost trade off. That paper proposes a novel approach for time–cost trade-off analysis of a project network in fuzzy environments. Different from the results of previous studies, in that paper the membership function of the fuzzy minimum total crash cost is constructed and fuzzy solutions are provided. The corresponding optimal activity time for each activity is also obtained at the same time. An example of time–cost trade-off problem with several fuzzy parameters is solved successfully to demonstrate the validity of the proposed approach.

Sou-Sen Leu [6] proposed a GA-based fuzzy optimal model for construction time-cost trade-off. A new optimal construction time-cost trade-off method is proposed in that paper, in which the effects of both uncertain activity duration and time-cost trade-off are taken into account. Fuzzy set theory is used to model the uncertainties of activity durations. A searching technique using genetic algorithms (GAs) is adopted to search for the optimal project time-cost trade-off profiles under different risk levels. The method provides an insight into the optimal balance of time and cost under different risk levels define by decision makers.

Daisy Zheng [7] introduced stochastic time–cost optimization model incorporating fuzzy sets theory and non-replaceable front. In that investigation, fuzzy sets theory is applied to model the manager's behavior in predicting time

Manuscript received September 12; revised November 5, 2018.

Hamed Naseri and Mohammad Ali Etebari Ghasbeh are with Iran University of Science and Technology (IUST), Iran (e-mail: hamed_naseri1993@yahoo.com, mohammadali_etebari@yahoo.com).

doi: 10.18178/ijimt.2018.9.6.826

and cost pertinent to a specific option within an activity. Genetic algorithms are used as a searching mechanism to establish the optimal time–cost profiles under different risk levels. In addition, the non-replaceable front concept is proposed to assist managers in recognizing promising solutions from numerous candidates on the Pareto front. Economic analysis skills, such as the utility theory and opportunity cost, are integrated into the new model to mimic the decision making process of human experts. A simple case study is used for testing the new model developed. In comparison with the previous models, the new model provides managers with greater flexibility to analyze their decisions in a more realistic manner. The results also indicate that greater robustness may be achieved by taking some risks.

Önder Halis Bettemir [8] used network analysis algorithm to trade-off between time and cost in projects. In that study, two projects (18 and 63 Activities) are tested and results revealed that the network analysis algorithm converges to optimum or near-optimum solution by only one percent of the computational demand of meta-heuristic algorithms. Consequently, the proposed heuristic algorithm is a convenient optimization method for the solution of time-cost trade-off problem.

ErikL Demeulemeester [9] described two algorithms, based on dynamic programming logic, for optimally solving the discrete time-cost trade-off problem. In deterministic activity on arc networks of the CPM type, where the duration of each activity is a discrete, non-increasing function of the amount of a single nonrenewable resource committed to it.

Ehsan Eshtehardian [10] investigated on stochastic time–cost trade-off problems. His study presents a new approach for the solution of time–cost trade off problems in an uncertain environment. Fuzzy numbers are used to address the uncertainties in the activities execution times and costs. Fuzzy sets theory is then explicitly embedded into the optimization procedure. A multi-objective genetic algorithm is specially tailored to solve the discontinuous and multi-objective fuzzy time- cost model with relatively large search space.

As it can be seen from all the references above, most of the previous investigations have been used time-cost trade-off analysis to plan the schedule of projects before starting them.

It is clarify, using time-cost trade-off analysis can help contractors to compensate delays or trade-off between increasing resources and paying delay punishment. In this paper, a new approach is presented for compensate delay of projects.

III. Problem Definition

As mentioned, the aim of the time-cost trade-off problem (TCTP) is to find best solutions which yield the optimal balances between time and cost of the project. In other words, the objective of TCTP is to find the most cost effective solution for each of the potential project durations and vice versa. According to the CPM, total time of the project is the duration of the most time consuming path of the project. Due to the fact that modes of implementing activities are not primarily chosen, the longest path is not identified beforehand [11].

To analyze improvement of projects and to compare the implementing work with time schedule, monitoring in definite times is required. TCTP can be used after each monitoring, because after checking out the projects, the critical (most time consuming) path may be changed by delays. Also, in some occasions the duration time of projects are increased and TCTP can be used to reduce the time of activities. Hiring extra workers and using more equipment help us to implement each activity in fewer time.

In this paper, a case study in considered to trade-off between delay (time) and delay punishment (cost). The activities ID and predecessors are presented in table1. Also, network of project is illustrated in Figure1. It is clarify that A-C-G-H-I-J-K is critical path and duration time of project is 45days. 15th and 30th days of project are considered as monitoring and controlling days. The aim of this study is to use time-cost trade-off analysis to minimize the total extra cost of project which should pay for delay punishment.

Fig. 2 represents the remaining activities in 1st monitoring day (15th day). Also Table II provides information about the remaining paths and their delays. As it can be seen from the Table II, G-H-I-J-K and L-M-N-O have 5 and 4 days delay respectively. The other paths will finish before deadline of project. So, the contractor has to pay 900 $ as 5 days delay punishment. Delay punishment was considered 180 $ for each day. In this situation, contractor can hire extra workers and buy new equipment to reduce Delay punishment. After investigation on different kind of resources, some modes are assigned for each activity. 1st mode is initial planning mode and paying extra money is not needed for this mode. In other modes, time of each activity can be reduced by paying extra money. If it is spent more money for each activity, the duration time of that activity is reduced more. Table III represents different types of implementing for all activities which are located in G-H-I-J-K or L-M-N-O paths (paths which have delay).

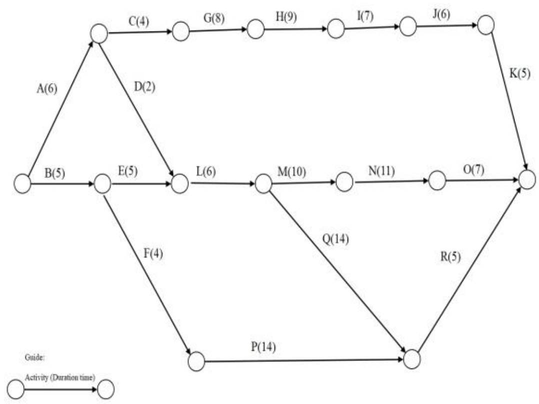

Fig. 1. Network of project.

TABLE I: Activities ID, Time and Predecessors

Activity ID	Predecessor	Duration time
A	-	6

B	-	5
C	A	4
D	A	2
E	B	5
F	B	4
G	C	8
H	G	9
I	H	7
J	I	6
K	J	5
L	D,E	6
M	L	10
N	M	11
O	N	7
P	F	14
Q	L	14
R	P,Q	5

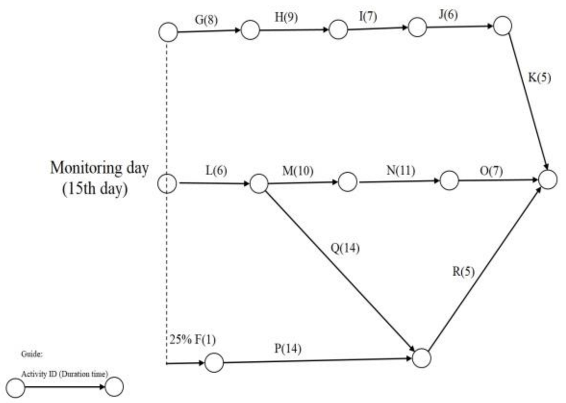

Fig. 2. Network of project for remaining activities in monitoring day.

TABLE II: DIFFERENT TYPES OF IMPLEMENTATION FOR ACTIVITIES IN DELAYED PATHS

Activity	Mode	Time (day)	Extra cost (US Dollar)
G	1	8	0
	2	7	100
	3	6	210
	4	5	430
H	1	9	0
	2	8	60
	3	7	130
	4	6	215
	5	5	400
I	1	7	0
	2	6	90
	3	5	200
	4	4	325
J	1	6	0
	2	5	105
	3	4	250
K	1	5	0
	2	4	160
L	1	6	0
	2	5	110
M	1	10	0
	2	9	100
	3	8	215
	4	7	400
N	1	11	0
	2	10	60
	3	9	180
	4	8	320
	5	7	480
O	1	7	0
	2	6	80
	3	5	210

IV. PROPOSED MODEL

In this introduced project, contractor should spend more money on extra resources to reduce delay punishment, if it is more economical. Trade-off between cost of delay punishment and delay time is considered in this model to minimize extra cost which should spent on project.

Each activity i has m_i modes. The time-cost pair of activity i for its v^{th} mode is $(t_{i,v}\ ,\ c_{i,v})$, where t_{iv} is the associated duration and c_{iv} is the associated cost. For any two modes $(i,\ v1)$ and $(i,\ v2)$, we assume $t_{i,v1} > t_{i,v2}$ implies $c_{i,v1} < c_{i,v2}$, i.e., shorter durations require extra resources, hence higher costs. Moreover, we assume $v1<v2$ implies $t_{i,v1} > t_{i,v2}$ for all i, that is, the activity modes are indexed in their decreasing order of durations [12].

The decision variables of this model are as follows:

$$y_{i,v} = \begin{cases} 1 & \text{if activity } i \text{ is assigned to mode } v \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Each activity are allowed to be assigned to exactly one mode. So:

$$\sum_{v=1}^{m_i} y_{i,v} = 1 \qquad i = 1, 2, \dots, Z \quad (2)$$

In each path, time is the sum of all activities time which are located in that path.

$$T_{Path} = \sum_{v=1}^{m_i} \sum_{s=1}^{Z} y_{s,v} \times t_{s,v} \quad (3)$$

where T_{Path} is the duration time of each path, and s are the activities which are located in the path. According to the equation (3), the duration time of two delayed path in our model are as follows:

$$T_{G-H-I-J-K} = T_1 = \sum_{v=1}^{m_i} y_{G,v} \times t_{G,v} + \sum_{v=1}^{m_i} y_{H,v} \times t_{H,v} + \sum_{v=1}^{m_i} y_{I,v} \times t_{I,v} + \sum_{v=1}^{m_i} y_{J,v} \times t_{J,v} + \sum_{v=1}^{m_i} y_{K,v} \times t_{K,v} \quad (4)$$

$$T_{L-M-N-O} = T_2 = \sum_{v=1}^{m_i} y_{L,v} \times t_{L,v} + \sum_{v=1}^{m_i} y_{M,v} \times t_{M,v} + \sum_{v=1}^{m_i} y_{N,v} \times t_{N,v} + \sum_{v=1}^{m_i} y_{O,v} \times t_{O,v} \quad (5)$$

Also, total extra cost that should be paid for project delay can be calculated based on equation (6):

$$Cost = \sum_{v=1}^{m_i} \sum_{s=1}^{Z} y_{i,v} \times c_{i,v} + U_{Pun} \times [Max\,(T_1, T_2) - 30] \quad (6)$$

$$i = 1, 2, \dots, Z$$

where U_{Pun} is the unit delay punishment which should be paid for each day delay. 30 is the deadline of project in 15th day. $c_{i,v}$ is the cost of each activity i for its v^{th} mode. Z is the number of remaining activities in delayed paths.

The aim of this study is to minimize the extra cost that should paid for project delay. According to the equation (6), our model should trade-off between cost of delay punishment and cost of increasing the resources.

V. Genetic Algorithm (GA)

Genetic algorithm (GA) is an evolutionary algorithm which perform optimization search in population to find better answers. It works based on Darwinian principles of natural selection that was introduced by John H. Holland [13]. Genetic algorithm is one the heuristic algorithms that find optimal or near optimal answers in short time. In evolution, the problem each species faces is to search for beneficial adaptations to the complicated and changing environment. In other words, each species has to change its chromosome combination to survive in the living world. In GAs, a string represents a set of decisions (chromosome combination), a potential solution to a problem. Each string is evaluated on its performance with respect to the fitness function (objective function). The ones with better performance (fitness value) are more likely to survive than the ones with worse performance. Then the genetic information is exchanged between strings by crossover and perturbed by mutation. The result is a new generation with (usually) better survival abilities. This process is repeated until the strings in the new generation are identical, or certain termination conditions are met [14].

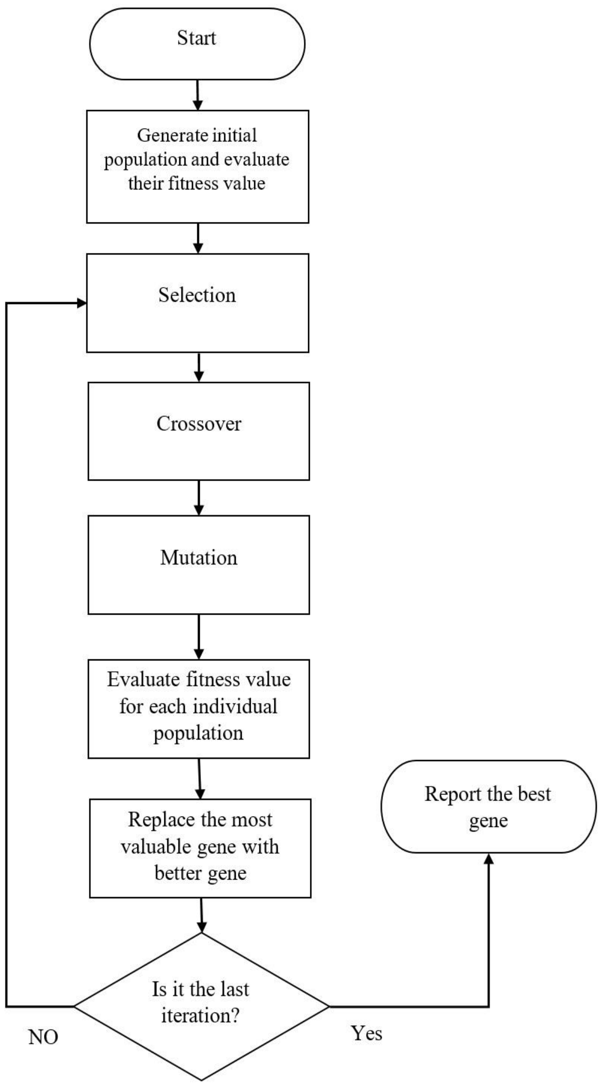

Fig. 3. Genetic algorithm flowchart.

In this paper, double point crossover is considered in duplications. Using suitable selection processors help the algorithm to find better answers and cover more data. Three selection processors (Tournament selection, Random selection, and Roulette wheel selection) are used to improve the efficiency and cover all data. In each selection, one of the mentioned selection processors is selected randomly. Also number of population size, number of iterations, crossover percentage, and mutation percentage are considered 50, 300, 0.8, and 0.2 respectively. The algorithm runs 5 times and the best answer is reported. Matlab Software 2016 version is used to make this model.

Genetic algorithm flow which is used in this model is presented in Fig. 3.

VI. Linear Programming (LP)

A linear programming problem is the minimization (or maximization) of a linear functional. The vast majority of LP problems include special linear inequalities that simply consist in the non-negativity constraints of some or all variables. Due to their particular nature these constraints are always stated separately from the other constraints. Variables not constrained to be non-negative are called free.

Dantzig used the Linear programming in algorithms for the first time [15]. The basic idea of the algorithm is to search an optimal vertex of the polyhedron by moving from a vertex to an adjacent better vertex until no improvement is possible. A vertex is the extreme point of a set of edges (this set may be empty) and also can be the extreme point of a set extreme rays (this set may be also empty, but at least one of the two sets must be nonempty). The whole set of edges and extreme rays needs to be explored to see whether there are any better vertices or there is an extreme ray along which the improvement is unbounded. In the latter case the algorithm stops reporting unboundedness, whereas in the former case it continues iteratively from a vertex to an adjacent vertex if this is better. In case no improvement is possible the algorithm stops returning the current vertex as the optimal solution [16].

In this model, LP is going to minimize equation (6). It is obvious, when the cost is minimized, T_1 is equal to T_2 because it is not economical to reduce the duration time of a path more than enough. So, in LP model T_1 is considered equal to T_2 to minimize equation (6). Lingo software 17 version is used to make this model.

VII. Results and Discussions

In this paper, the aim is to minimize extra cost that should pay for delay punishment. In this case study, contractor has two alternatives: 1. pay for delay punishment, 2. Reduce or remove the delay of project. So, time-cost trade-off analysis is considered to minimize the extra cost that contractor should spent on project. Linear programming and Genetic algorithm are used to minimize the extra cost which is introduced in equation (6).

GA is run 5time and the best answer is reported. Also LP runs and the optimal mode of activities for two model are presented in Table3. In both optimal answers, the modes of G, H, I, J, K, L and N are the same but the modes of M, and O are different for these introduced answers.

The extra cost and delay of optimal models are presented in Table IV. The convergence of cost in Genetic algorithm is illustrated in Fig. 4. According to Table IV, Linear programming provides better solution because its introduce model is cheaper than that of Genetic algorithm. In both introduced model, delay is considered 2 days. So, duration time of project is reduced 3days.

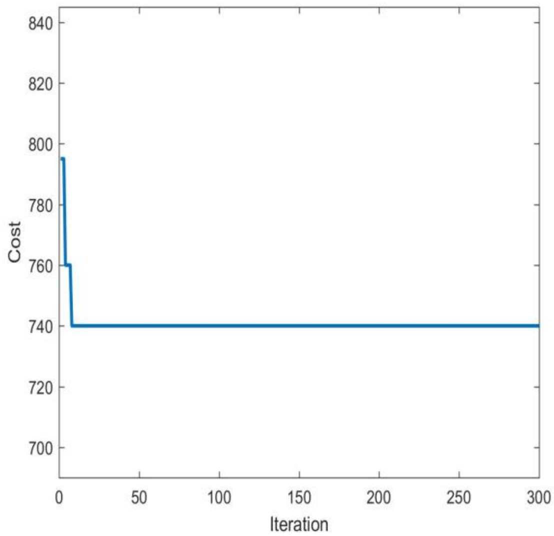

Fig. 4. The convergence of cost for genetic algorithm.

TABLE III: Optimal Modes which are Introduced by GA and LP

Activity	Mode	
	Genetic algorithm	Linear programming
G	1	1
H	3	3
I	2	2
J	1	1
K	1	1
L	1	1
M	2	1
N	2	2
O	1	2

TABLE IV: COST AND DELAY OF OPTIMAL SOLUTIONS WHICH ARE INTRODUCED BY GA AND LP

	Genetic algorithm	Linear programming
Cost (US dollar)	740	720
Delay (days)	2	2

VIII. CONCLUSION

In this Paper, we investigate on the cost that should pay for delay of projects. Trade-off analysis is used to make balance between delay punishment's costs and increasing resource's costs. In this introduced model, a case study is considered to analyze the efficiency. Genetic algorithm and Linear programming are used to introduce optimal solutions.

The following conclusions can be drawn from the results of this study:

- To compensate the delay of projects and to spend extra money on projects, time-cost analysis is a powerful and useful technic to reduce the expenditure.
- Paying extra cost for delay punishment is not recommended in all situations. Sometimes hiring new workers and adding extra equipment can be much more economical.
- Increasing resources to remove delays is not suggested in all projects. In some situations, paying for delay punishment can be more economical. So, trade-off between them is necessary for minimizing the cost.
- Linear programming provides optimal answer and it is a powerful algorithm for this model. The efficiency of Linear programming is more than that of Genetic algorithm because it provides cheaper solution. However, Genetic algorithm provides near optimal solution.
- Linear programming and Genetic algorithm reduce 20% (from 900$ to 720%) and 17% (from 900$ to 740$) of extra cost that should pay for delay punishment respectively. Also in their introduced solutions, delay of project is reduced 60 percent.
- The speed of algorithms is one of the most important criteria to compare them. In this introduced model, Linear programming is much faster than Genetic algorithm. Linear programming runs in 0.05 second. However, Genetic algorithm average running time is 1 second for 300 iterations approximately.

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Hamed Naseri was born in Tehran, Iran, in 1993. He received the B.Sc degree in civil engineering from Arak university in 2015. He is a graduate (M.Sc.) student. He is majoring in civil engineering – construction management- at Iran University of Science and Technology (IUST). He worked in Naghshe Radis Mandegar in charge of Site supervision between 2015 and 2016. He published his book – Nanotechnology utilization in concrete industry – in 2018. His research interests include resources optimization, project management, project controls and risk mitigation, building information modeling technologies, smart building and internet of things, green building and environmentsLabor productivity in construction management.

Mohammad Ali Etebari Ghasbeh was born in Tehran, Iran, in 1994. He received the B.Sc. degree in civil engineering from Shahed university in 2016. He is a graduate (M.Sc.) student. He is majoring in civil engineering – construction management- at Iran University of Science and Technology (IUST). His research interests include resources optimization, concrete technology, prediction of project features, time management is projects, project management, smart building and internet of thingsgreen building and environments.