A preemptive goal programming approach for developing a cost-time trading-off model based on tolerated cost

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Abstract

Since, cost and time are known as two main factors in civil engineering projects, the aim of this study is to optimize the relationship between the above factors. In optimization process, a cost tolerance is considered to achieve a wide-range of time-cost trading off while trapezoid fuzzy numbers are used for time and cost over the project activities. Preemptive goal programming approach has been utilized to develop mathematical model and a Weigh In Motion system (WIM) in Isfahan-Nain road has been selected as case study. The proposed model has been utilized using a wide range of cost tolerance and results revealed that the proposed model is capable to identify the relationship between cost and time in construction projects. Decision makers who are dealing with these kinds of problems are recommended to apply the proposed model to achieve the best situation of project scheduling plan.

Keywords
Preemptive Goal Programming, Project Management, Cost-Time Trade-off, Tolerated Cost

1. Introduction

Project management is one of the most important fields in business and industry. In all organizations, every task can be taken into account as a project, i.e. a temporary endeavor undertaken to produce a unique product or service (Lewis, 2010).In this context, the purpose of the project management is to foresee or predict as many dangers and problems as possible and to plan, organize, and control activities so that projects are completed successfully in spite of all the risks (Lock, 2007).Many researchers have attempted to define project management but according to PMBOK Guide, nine knowledge areas in project management are project integration, time, cost, quality, human resources, communication, risk and procurement management (PMI, 2008).One important aspect of project management is to know about the information related to the optimum balance between the project's objectives. Since, according to the iron triangle, time, cost and quality are important objectives of a project, extensive researches are focused on developing a cost-time trade-off problem in which cost and time have mutual relationships over the project management concerns. The aim of a time-cost trade-off problem is to select a set of activities and an appropriate execution mode for each activity so that the cost and time of the project are simultaneously optimized (Razaviet al,2015).

Cost-time balancing problem for the first time was presented by Kelly in 1961 by taking a linear relationship between time and expense activities were discussed(RaviShankar et al,2011).Research in this area has led to the use of different methods to solve the balancing problem of the cost. Methods and optimization algorithms are divided into two categories including exact and approximation algorithms. The exact algorithms are usually mathematical methods while approximate solution algorithms are including innovative methods and innovative techniques which are mainly used in complex systems (Taha, 2008).The success of accomplishing innovative ways to solve problems generally depends on the type of problems but not guarantee to reach to the optimal solution. In these methods, researchers are getting to achieve practical approach and experimental results. Innovative methods can also be provided by experimental methods to reach near optimal solutions (Vanhoucke, 2007).If mathematical methods are unable to solve the problem or they are difficult to be used, the answer is determined to ensure near optimum solution. Mathematical methods include the method used for linear programming, goal programming, integer programming, dynamic programming and linear programming and mixed integer programming model also pointed out. With increasing size and complexity of the issues, the possibility of solutions using mathematical optimization will be decreased. That's the way that in recent years the use of meta-heuristic method is getting to be more common. One of these methods can be genetic algorithm optimization of bird populations, Leap Frog and optimization of ACS noted in (Feng et al,1997).

Since estimated time and completion time for any activity are two basic elements of that, computing networks constitute the project management, needs accurate results for estimation of project schedule which play important role in the next steps' calculations. One of the essential ways to estimate the time and cost activities is the use of fuzzy theory. Fuzzy numbers in various research projects can be used to show uncertainty by taking the uncertainty in the parameters of the decision to close the timing models used to project into reality. (Zadeh, 1965).

On the other hand, different techniques have also been used for multi-objective problems. One way to solve problems on multiple targets and planning is multi-objective programming models (Taha, 2008). One type of goal programming, goal programming method is prioritized. In this way the decision should be defined as goals in the importance orders of the package. In this method with considering many objective functions, targets are solved step by step following the high priority to the lowest one while in each step low priority function is used with another purpose (Taha,2008).

(Babu& Suresh, 1996) were the first who suggested that the quality of a completed project may be affected by project crashing. For the sake of simplicity, they adapted the continuous scale from zero to one to specify quality attained at each activity. The overall project quality is a function of quality levels attained at the individual activities. They developed optimization models involving the project time-cost-quality trade-off which would assist in expediting a project weighing time-cost-quality triangle. Each of the three developed models optimizes one of these three entities by assigning desired levels (steps) comparing to the other attributes.

Tolerated optimizing technique of goal programming has been utilized for solving hazardous materials routing problem and determining the best locations of hazardous material distribution centers (Mahmoudabadi et al, 2016). Their mathematical model provided the best route for hazardous materials transportation at the lowest cost and the best place to determine the distribution centers of fuels. Given the importance of risk transport of hazardous materials, it is considered as the first objective function to achieve the minimum target of network risk. Minimizing transport cost was regarded as second objective function while risk tolerance considered in optimizing cost phase. In this field, (Iranmanesh et al, 2008) tried to determine optimal solutions from which the project manager will select his desirable choice to run the project. Their problem was a multi-objective problem and the purpose was to find the Pareto optimal front of time, cost and quality of a project and a meta-heuristic method is developed based on a version of genetic algorithm specially adapted to solve multi-objective problems namely fast PGA.

(Tavana et al, 2013) have vision to consider the trade-offs between conflicting objectives in project scheduling problems (PSPs) is a difficult task. They proposed a new multi-objective multi-mode model for solving discrete time–cost–quality trade-off problems (DTCQTPs) with preemption and generalized precedence relations. Their proposed model has three unique features: (1) preemption of activities (with some restrictions as a minimum time before the first interruption, a maximum number of interruptions for each activity, and a maximum time between interruption and restarting); (2) simultaneous optimization of conflicting objectives (i.e., time, cost, and quality); and (3) generalized precedence relations between activities. The above mentioned assumptions are often consistent with real-life projects. A customized, dynamic, and self-adaptive version of a multi-objective evolutionary algorithm is proposed to solve the scheduling problem. The proposed multi-objective evolutionary algorithm has been compared to an efficient multi-objective mathematical programming technique known as the efficient ε-constraint method. The comparison is based on a number of performance metrics commonly used in multi-objective optimization. Their model results showed the relative dominance of the proposed multi-objective evolutionary algorithm over the ε-constraint method.

I another research work in this area, it is concluded that a poor quality affects project make span and its total costs negatively, but it can be recovered by repair works during construction (Fang Fu et al, 2016). A non-linear programming model has been developed based on the classic multi-mode resource constrained project scheduling problem considering repair works. In order to obtain satisfactory quality without a high increase of project cost, the objective is defined to minimize total quality cost which consists of the prevention cost and failure cost according to Quality-Cost Analysis. A binary dependent normal distribution function is adopted to describe the activity quality; Cumulative quality is defined to determine whether to initiate repair works, according to the different relationships among activity qualities, namely, the coordinative and precedence relationship. Furthermore, a shuffled frog-leaping

algorithm is developed to solve this discrete trade-off problem based on an adaptive serial schedule generation scheme and adjusted activity list. In the program of the algorithm, the frog-leaping progress combines the crossover operator of genetic algorithm and a permutation-based local search. Finally, an example of a construction project for a framed railway overpass is provided to examine the performance of the proposed algorithm, and it assists in decision making to search for the appropriate make span and quality threshold with minimal cost.
(Razaviet al,2015) converted a balancing cost-quality-time problem to a goal programming method. Their balancing problem in the form of a gray model of multi-objective integer expressed several modes for any activity. To demonstrate the capabilities of its models, both optimistic and pessimistic concerns have been investigated. Optimistic in any activity in the shortest time, at the lowest cost and highest quality will be done in the pessimistic mode with the highest costs, with the highest quality which can be also observed in (Afshar et al, 2007) while a multi-objective ant colony optimization model has been developed to analyze the advanced time cost-quality trade-off problem.(Abbasnia et al, 2008) investigated a new approach in solving time-cost trade-off problem, because of uncertainties which affect activity cost. Fuzzy logic theory is employed to consider uncertainty affecting total direct and indirect cost of a construction project. Non-dominated Sorting Genetic Algorithm (NSGA) is applied to provide a trade-off between time and total cost.
In this research work, time-cost balancing problem of a civil engineering project is developed considering a tolerated cost over time scheduling problem. Duration of project activities and their costs are defined by trapezoidal fuzzy numbers because of considering the uncertainty concerns can be expressed by the nature of fuzzy numbers. Minimizing project total cost and minimizing the duration of the project optimized have been defined on two different levels and the relationships between activity time and its cost is considered as quadratic equation relevant to time and cost. In this case, objective function is to minimize the cost of the project at the first level, with respect to its importance, the second level is the minimum duration of the project by the tolerance of project cost. An experimental construction project of installing Weight In Motion system (WIM) in Isfahan-Nain express way has also been selected as case study and results have been analyzed using different tolerances.

2. Developing Mathematical Model

As aforesaid, the duration of each activity has been defined as trapezoidal fuzzy numbers (a, b, c, d) considered and in any case the operating cost also includes an arrangement with C (a), C (b), C (c), C (d) shown in figure 1. By increasing the duration of each activity, cost is increased (pessimistic time duration case). On the other hand if the activity is too low, operating costs are also increased (optimistic time duration case). So the cost of their activities in pessimistic and optimistic time frames is displayed as figure 1 in which the relationship between cost and duration of activity is used by a quadratic chart.
In this case, the relationship between time and cost can be defined as a quadratic equation numbered as equation (1). Any quadratic equation contains some coefficients defining variables and related power factors.

$$C(\mathrm{T}_i) = \beta_{2i}(\mathrm{T}_i)^2 + \beta_{1i}(T_i)^1 + \beta_{0i} \quad (1)$$

Where:

β_{2i} : The second time power factor for activity i in operating cost.

β_{1i} : The first time power factor for activity i in operating cost.

β_{0i} : Constant coefficient of cost for activity i.

Decision variable: Since the completion time of projects from the starting stage of activities is generally used as a decision variable, the earliest onset time and duration of activity can be defined as decision variables as below:
X_i= The earliest start time of activity i
T_i= Duration of the activity i
It is necessary to be mentioned that duration for each activity should also defined as a variable in which the activity time is optimized using mathematical model.

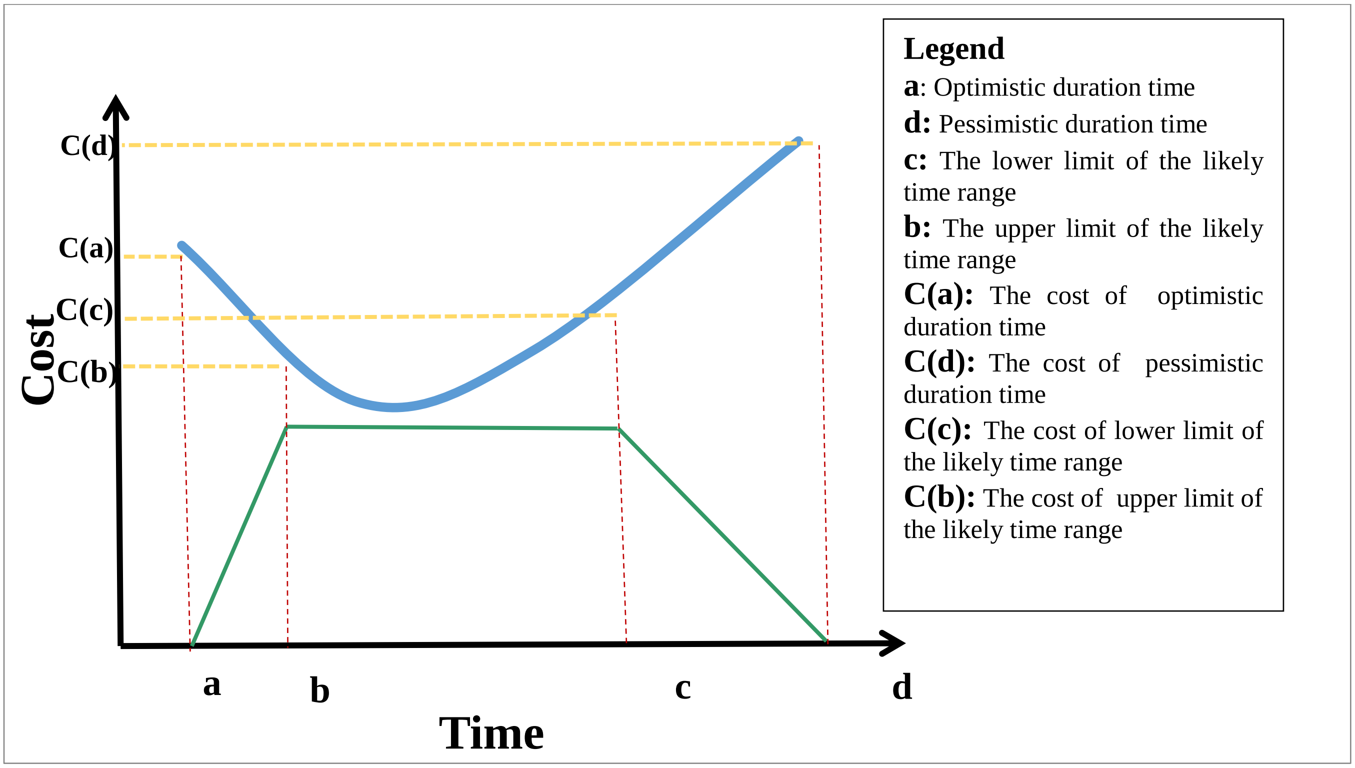

Figure 1: The relationship between the cost and duration of activity

Parameters: Coefficients of quadratic curves associated to activities are considered as parameters. Time optimistic, pessimistic, and the probable activity duration times are defined as parameters in the model expressed more as below:

$lowT_i$: Optimistic duration time to carry out the activity i defined as the first trapezoidal fuzzy number (a).

$medT1_i$: The lower limit of the likely time range for activity i defined as the second trapezoidal fuzzy number (b).

$medT2_i$: The upper limit of the likely time range for activity i defined as the third trapezoidal fuzzy number (c).

$uppT_i$: Pessimistic duration time to carry out the activity i defined as the first trapezoidal fuzzy number (d).

Goal1: The first objective function of cost obtained by duration times of activities over the project.

Alpha**:** Criteria for acceptable range (tolerance factor) that allows cost optimization project cost in the second stage (at the time) from the obtained value of the objective function.

$V_1(J, I)$: Variable coefficients which express the sequential order of activities. It is a binary parameter, in which the coefficient is 1 or -1 if there is sequential order on activities and 0, otherwise.

$V_2(J, I)$: Variable coefficients which express the time relationship between each sequential activity. It is also a binary parameter, in which the coefficient is 1 or -1 if it is necessary that time of activity is considered the parameter is set to 1, and zero, otherwise.

First objective function: The whole objective function is expressed in two different levels and includes two target of minimizing cost in the first level and minimizing the project duration time at the second level. Equation (2) represents the first level of objective function in which the total cost of project is minimized according to the time assigned for each activity.

$$\text{Min } Z_1 = \sum_{i=1}^{n} C(T_i) = \sum_{i=1}^{n} (\beta_{2i}(\mathrm{T}_i)^2 + \beta_{1i}(T_i)^1 + \beta_{0i}) \tag{2}$$

Constraints: In order to achieve the goal of minimizing the cost, there are some constraints including:
1. Each activity in the project network may have some prerequisites that are effective for setting earliest start times. These constraints by activity-coefficients prerequisite $V_1$and V_2in previous section have stated. In this case, activity i shall not be less than the sum of the earliest start time activity (j) (formerly active i), and the duration of activity (j) is. V_1 factor for the earliest start time of i-fold (+1), a prerequisite for activity (j) to (-1) is. V_2 factor to do the task i equal to (+1). Equation (3) expresses the above mentioned constraint over the project.

$$V_1(X_i - X_j) \geq V_2(T_j) \tag{3}$$

As a prerequisite for starting any activity, equation (4) should be defined as below:

$$X_1 = 0 \tag{4}$$

2. The duration of each activity in the time domain is defined in the low (optimistic time) and the high (pessimistic time). So, the time assigned for each activity duration should not be unbounded. This constraint can be formulated as equation (5).

$$lowT_i \leq \mathrm{T}_i \leq uppT_i \tag{5}$$

The output of the above developed model is to set time duration for all activities as well as project total completion cost in minimum rate. For the rest, cost will be bounded to optimize total time.

Second objective function: After achieving the first objective which was to minimize the total completion cost, the next priority objective function Z_2will can be formulated as equation (6). In the network structure of the project consists of n activities, a virtual activity (with cost and duration of zero) is defined to minimize its earliest start time X_{n+1}, the minimum total duration of the project. The second objective function (6) states:

$$Min\ Z_2 = Max(X_{n+1}) \tag{6}$$

The obtained value of the first objective function is inserted as the additional constraint assuming the tolerance of cost defined as equation (7). The new constraint is defined the optimum value of the objective function is achieved, introduced to goal($Z_1 = goal1$) and for this value takes into account a tolerance(Alpha) allowsthe optimal value achieved in the first level of the project cost as defined variations (tolerance) or more.

$$\sum_{i=1}^{n} C(T_i) \leq (1 + Alpha) * \mathrm{goal1} \tag{7}$$

The other constraints which are defining the sequential orders on project activities should be considered over the second phase of modeling.

General model: Following what mentioned above, and identifying the decision variables, parameters, constraints and two levels objective functions, the overall model can be expressed as follows:

$$Level1\ : Min\ Z_1 = \sum_{i=1}^{n} C(T_i) = \sum_{i=1}^{n} (\beta_{2i}(T_i)^2 + \beta_{1i}(T_i)^1 + \beta_{0i})$$

$$Level\ 2: Min\ Z_2 = Max(X_{n+1})$$

S.t:

$$V_1(X_i - X_j) \geq V_2(T_j)\ \forall i = 1, 2, \ldots, \mathrm{n},\ \mathrm{j} \in \mathrm{iformerly}$$

$$X_1 = 0$$

$$lowT_i \leq \mathrm{T}_i \leq uppT_i \ \forall i = 1, 2, ..., \mathrm{n}$$

$$\sum_{i=1}^{n} C(T_i) \leq (1 + Alpha) * \mathrm{goal1}$$

3. Case Study

Installing a weighing in motion system in Isfahan-Nain expressway in the Iranian central province of Isfahan has been selected as case study to validate the proposed model. Weighting in motion systems is named as facilities which are able to measure the weight of vehicles without stop (Non-stop control devise). These systems have the ability to weighing at different speeds, so that weighting in motion system can be divided into three groups:

- Weighting in motion systems at low speeds (Speed limit to 16 mph)
- Weighting in motion systems at average speeds (Speed range of 16-48 mph)
- Weighting in motion systems at high speeds (Speed of about 88 mph)

Also, some weighting in motion systems have the ability to transfer data to control stations, so depending on the conditions of these systems, they can be used in different locations (American Society for Testing and Materials, 2002). While there are many applications collect traffic information in the planning, design and management of roads, the main objectives of the Weighting in motion systems can be divided into two main goals, which include collecting traffic information and applying the overloading law (Belfield et al, 1999).

Activity cost and time is considered as trapezoidal fuzzy numbers. As previously stated, the relationship between the time and cost of activity is defined as a quadratic equation and calibration has been done for providing power supply is expressed as equation (8).

$$\mathrm{C}(\mathrm{T}_i) = 1.3333(T_i)^2 - 6.8333(T_i) + 43 \quad (8)$$

The proposed model has been utilized for experimental data using the well-known optimization software of GAMS. The time duration of each activity and project earliest starting time as well as the objective function value are obtained to be a set in accordance with the project plan shown in table 1. Running the model, the cost of any activity will also be indicated shown at the last column. In Table 1 the earliest start time, duration and cost of any project activity has been expressed at this level. Earliest starting time and time duration are defined by two parts of month and additional days for each activity which is shown in parenthesis in columns 3 and 4. The second objective function is (to minimize the duration of the project) by taking different amounts of tolerated cost (Alpha) can be given in a different amounts tabulated in table 2. In Table 2, the values of objective functions for amounts (0.5-0) = Alpha = 0.15 are shown. The level remains constant and does not change the duration of the project. At this level, total project cost and duration of the project is to arrange 1221 million USD and at least 12 months for project completion.

1. Summary and Conclusion

In the present paper, a time scheduling process for civil engineering projects has been developed utilizing preemptive goal programming approach in which a tolerance is considered for cost variation over the project. The proposed model has been run using experimental data gathered from a weigh in motion system and results have been analyzed. Results showed that the proposed model can be used for all project in which decision makers are dealing with trading-off between time and cost or any attributes may be defined in project scheduling. More researches are now conducted under the supervisory of the second author in which quadratic equation of cost may be should be formulated as bounded constraints to ensure that the cost will not be considered less than the minimum amount of cost is set for probable time duration. Researches who are interested in working in this field are recommended to develop mathematical models to ensure that more attributes are satisfied over the project such as risk, quality and so on.

Table 1: Scheduled time activities of project using Alpha = 0.15 (Cost: Million USD)

Activity Code	Activity Description	Earlier Starting Time	Duration of Execution	Activity Completion Cost
A	Installing the necessary approval review	0	1	0
B	The whole system is installed on a network location	1	1	0
C	Location system installed in the bow part	2	1	0
D	Supply of road pavement perfect platform for system installation	3	1	613.5
E	The project is designed to install in place	4	1	27.7
F	Network communications and information systems	5	1	47.5
G	Operation of construction (foundation and rig)	5	4 (21)	54
H	Supply and installation of detection sensors weight, speed and vehicle class	5	4 (11)	294.2
I	Power supply	6 (7)	1	37.5
J	Communications infrastructure	7 (7)	1	8.5
K	Tender for the supply and installation of hardware and software for the control canter	6	1	0
L	Supply and installation of hardware and software for the control canter	8 (7)	3 (23)	51
M	Weighing supplying software systems, license plate reading, by grade and speed	7	1	37.5
N	Launching systems, installed software and hardware	8	2	29.6
O	Calibration	10	1	13.5
P	Temporary delivery	11	4 (13)	6.6
Q	End	12	0	0
Project			12	1221

Table 2: The obtained values of objective functions (Time completion and cost)

Tolerance (α)	Optimized Completion Time	Optimized Cost Regarding α
∝= 0	29 (11)	1074.7
∝=0.02	20	1096.2
∝=0.05	16 (16)	1128.4
∝=0.1	13 (14)	1182.2
∝= 0.15-0.5	12	1221

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Samira Khoshnoud has Bachelor and Master of Science degrees in Industrial Engineering. She graduated from MehrAstan University, Guilan, Iran in July 2016. Her thesis dissertation is on studying cost-time trading-off in civil engineering projects and published two papers in this field.