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Multi-objective optimization of time-cost-quality-carbon dioxide emission-plan robustness in construction projects

Nahid Farazmand[1], Mohammad Ali Beheshtinia[1]*

[1]*Industrial Engineering Department, Semnan University, Semnan, Iran*

nahidfarazmand@gmail.com , beheshtinia@semnan.ac.ir

Abstract

Today, the construction industry is facing intense competition and success in this competition depends on several factors. Project managers try to minimize project time and cost, carbon dioxide emission and at the same time maximizing the quality of project and its plan robustness. In this paper, study construction project scheduling considering a discrete trade-off between time, cost, quality, carbon dioxide emission and the plan robustness. After presenting the mathematical model of the problem, a genetic algorithm inspired from the role model concept in sociology named Reference Group Genetic Algorithm (RGGA) is used to solve the problem. The "reference group" concept is introduced by a sociologist named Robert K. Merton. He believed that some people in each society such as heroes or entertainment artists affect other people. To evaluate the impact of "reference group" concept in genetic algorithm, RRGA is compared with a similar genetic algorithm that do not use this concept. The originality of this paper is introducing a new multi-objective project scheduling problem, presenting its mathematical model and adapting RGGA to solve it. The computational experiments show that using this concept improves the result.

Keywords: Genetic algorithm, project scheduling, project quality, green project, plan robustness

1- Introduction

Time-cost trade-off is considered as one of the most important aspects of planning and controlling the construction projects and so far, several different techniques have been used to solve this problem (Mokhtari and Hasani, 2017). It should be noted that the time-cost trade-off problems can be divided into two categories: continuous time-cost trade-off problems and discrete time-cost trade-off problems, which discrete time-cost trade-off problems are considered as NP-Hard problems (Liu et al., 1995). On the other hand, with the progress of the investigation and increase of the need to solve the problems in practice, researchers have focused on development of methods to solve the discrete time-cost trade-off problems (Tavana et al., 2014).

*Corresponding author
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In the present study, the desired problem is defined as discrete, and a meta-heuristic algorithm based on genetic algorithm is presented to solve the time-cost trade-off problem. It should be noted that, in recent years, in addition to time and cost, other factors were also important for project managers. For example, nowadays with the advent of new types of contracts, which led to increasing pressure to maximize the quality of the project, researchers have stated that, in addition to time and cost, they must also consider the quality of projects (Iranmanesh et al., 2008). In present study, along with the time and cost, quality is evaluated as an objective function. On the other hand, in recent years, the construction industry has been accused to create a wide range of environmental problems, such as high consumption of world resources and polluting the environment and greenhouse gas emission, among them, carbon dioxide is the most important gas produced in construction materials production process (Liu et al., 2013). In this study, to evaluate the environmental impacts of construction projects, inspired by the method presented in the paper (Liu et al., 2013), the amount of carbon dioxide has been investigated in the construction industry. In present study, along with four objectives presented, the plan robustness is considered as the fifth objective function. The less critical activities and paths the schedule develops for the project, the higher the ability to interrupt the activities without causing delays in the completion of the project, and it should be noted that, being critical or non-critical activity is determined due to its slack. In present study, this criterion is used as the fifth objective function.

This paper studies construction project scheduling with minimizing cost, time and carbon dioxide emission and maximizing quality of project and its plan robustness. This universality does not appear in any of the previous researches in this area.

After presenting the mathematical model of the problem, a genetic algorithm named Reference Group Genetic Algorithm (RGGA) is used to solve the problem. RGGA is introduced by Beheshtinia et al. (2017) and uses the concept of reference groups in society. Robert K. Merton is a sociologist who presented the concept of reference groups in society. He believed that some people in each society such as heroes, entertainment artists, etc. affect other people as role models. RGGA employs this concept in the search procedure of genetic algorithm.

The paper continues as follows: In the second section, theoretical and practical background of studies in this field is presented. Research method and problem assumptions are given in section 3. The result of applying the research steps are mentioned in Section 4, and conclusions of the study are presented in section 5.

2- Literature review

In general, since 60s, the CPM algorithm is used for the planning and controlling the construction projects, and since then, various techniques have been developed to improve it. Among these algorithms and techniques, time – cost trade-off is considered as one of the most important techniques to improve the CPM to plan and control projects (Liu et al., 1995).

So far, many exact or estimated methods have been developed for trade off problems with small size. In general, the methods for solving discrete cost-time problems are divided into three categories: **1.** The exact algorithms, such as linear programming, integer programming, dynamic programming, branch and cut algorithms (Pollack-Johnson and Liberatore, 2006); **2.** Heuristic algorithms (Vanhoucke and Debels, 2007); **3.** Meta-heuristic algorithms (Ke, 2014).

In present study, the desired problem has been defined as discrete and Reference Group Genetic Algorithm has been used to solve it, which is one of the meta-heuristic algorithms. In recent years, researchers have stated that, in addition to time and cost, they must also consider the quality of projects (Iranmanesh et al., 2008). For instance, in recent years, government agencies, have adopted new innovative contracts which based on them incentives are considered to improve the quality of construction projects (Mungle et al., 2013). In present study, quality along with the time and cost is evaluated as an objective function. In most construction projects, key factors for success are determined based on factors such as time, cost and quality, and decision-makers rarely consider environmental issues in their projects (Liu et al., 2013). According to Acquaye and Duffy (2010), in 2005, in Ireland, 13.81 million tons CO2eq was produced in the construction sector, and this is equivalent to 11.7 percent of total Carbon dioxide emissions in the country, including 2.37 million tones direct emissions on the project site (17%), 5.69 million tones indirect emissions resulting from the production of building materials in Ireland (41%) and 5.75 million Tons of indirect emissions has been resulting from the production of building materials in other countries. Environmental impact of buildings construction and energy consumption is very significant in the production process and transportation of building materials and the construction of buildings and as a result, greenhouse gas emissions (Yan et al., 2010). It should be noted that, although many studies have been conducted on calculating the amount of carbon dioxide emissions in the construction industry and its environmental impact, but still there is not an efficient and effective decision support system to help decision-makers to choose the optimal solution to deal with the environmental impact and reduce carbon emissions and in few researches, attention to environmental impacts has been taken into account along with factors such as the cost and duration of projects. This study uses research conducted by Liu et al. (2013), with the objectives of cost, time and quality and adds the carbon dioxide emissions of the construction processes and materials used in these processes. In addition to what was stated above, in the present study, in addition to four objective functions introduced, the plan robustness is also intended as a fifth objective function. Whatever the schedule developed for the project has fewer directions or critical activities, the ability to preemption and avoiding delays in the completion of the project will be higher, and it should be noted that, being critical or non-critical activity is determined due to its slack. Here, the weighted slack measure has been used to maximize robustness. To investigate the effect of project uncertainties on time and cost of activities Pathak and Srivastava (2014) proposed a new method based on the fuzzy logic and hybrid meta-heuristics (HMH). Input uncertainties considered being fuzzy and HMH were used to find Pareto front. Computational results show that the proposed method works efficiently for real world problems.

To recognize the most effective parameters for project scheduling Gálvez and Capuz-Rizo (2016) applied several global sensitivity analysis methods and found that the proper techniques were standardized regression coefficients, the Morris and Sobol'-Jansen. A multi-objective model was proposed by Mohammadipour and Sadjadi (2016) to minimize three objectives “total extra cost”, “total quality reduction” and “total risk increase” with time constraint. They used goal attainment technique to solve this mixed integer linear programming.

For scheduling repetitive projects Tran et al. (2017) introduced a novel method called “opposition multiple objective symbiotic organisms search” (OMOSOS) which used an opposition-based learning technique for generation jumping and population initialization. Moreover, to determine the project objectives containing time, quality, cost and interruption, they integrated a scheduling module. Oztemel and Selam (2017) proposed a Bee-based model to identify the minimum completion time for mold scheduling with multi-mode, single-resource and resource constraints. Tritschler et al. (2017) presented a Hybrid Metaheuristic (HM) for the resource-constrained project scheduling problem that has flexible resource profiles. To create feasible schedules, the HM used the Flexible Resource Profile Parallel Schedule Generation Scheme (FSGS) which utilized the concepts of non-greedy resource allocation and delayed scheduling. Wood (2017) proposed a model to optimize the total-project cost, duration and quality in Stochastic time-cost-quality tradeoff problem (STCQTP) with uncertainties by applying fuzzy analysis of quality item and a memetic algorithm including ten metaheuristics to combine the local and global duration-cost feasible solution space.

A multi-objective two-archive memetic algorithm was proposed by Shen et al. (2018) based on Q-learning (MOTAMAQ) for adjusting to changing environments of the dynamic software project scheduling. Main objectives were defined as employee’s satisfaction as well as project cost, robustness, stability, and duration. Their multi-objective dynamic software project scheduling problem model lacked the ability to extract all uncertainties, factors and dynamic events that could influence scheduling environments. In table 1, the history of research done to solve the trade-off problem is given. As seen in the table, some of the articles studied in this table, in addition to time and cost, have considered the quality of projects, as well, and meantime, only two papers have discussed reduction of the environmental impacts of construction projects in their modeling, and despite the fact that none of the investigated references have modeled the quality of the project and the environmental effects of the implementation of the project at the same time. In addition, the problem could be divided in two discrete and continuous problems.

The literature shows that no research considers the project scheduling problem with a trade-off between time, cost, quality, carbon dioxide emission and the plan robustness. Also, looking at table 1, the genetic algorithm is the most used algorithm to solve the problem, and this explains the popularity of the aforementioned algorithm for solving trade-off problems. In this study, also a new genetic algorithm is proposed to solve the mathematical model.

The innovations of this study can be stated as follows:

1) Study a new project scheduling problem with 5 different objective functions;
2) Presenting the mathematical model of the considered problems;
3) Adapting RGGA to solve the problem.

Table1. Review of related researches

Discrete problem	Continuous problem	Single Objective	Multi objective	With quality objective	With environmental objective	Use of Genetic algorithm	Reference
*		*		*			(Pollack-Johnson and Liberatore, 2006)
	*	*					(Nikoomaram et al., 2010)
*		*					(Klerides and Hadjiconstantinou, 2010)
*			*	*			(Zhang and Xing, 2010)
*			*	*		*	(Pour et al., 2010)
	*	*					(Chen and Tsai, 2011)
*			*				(Kalhor et al., 2011)
*		*					(Mokhtari et al., 2011)
	*	*					(Klanšek and Pšunder, 2012)
*		*				*	(Sonmez and Bettemir, 2012)
*			*		*	*	(Xu et al., 2012)
	*	*					(El-kholy, 2013)
*			*	*		*	(Mungle et al., 2013)
*			*			*	(Nabipoor Afruzi et al., 2013)
*			*		*		(Liu et al., 2013)
	*	*				*	(Ke, 2014)
	*		*			*	(Pathak and Srivastava, 2014)
*			*	*		*	(Tavana et al., 2014)
*			*	*		*	(Monghasemi et al., 2015)
*		*					(Said and Haouari, 2015)
	*		*			*	(Pathak and Srivastava, 2014)
	*	*					(Gálvez and Capuz-Rizo, 2016)
	*		*	*			(Mohammadipour and Sadjadi, 2016)
	*		*	*		*	(Tran et al., 2017)
*		*					(Oztemel and Selam, 2017)
*		*				*	(Tritschler et al., 2017)
	*		*	*	*		(Wood, 2017)
	*		*		*		(Shen et al., 2018)

3- Research method

In this section after presenting the problem statement, the research steps are described.

3-1- Problem definition

Assuming the trade-off problem to be discrete, on one hand, because of the proximity to what is done in practice, and on the other hand, due to the ability to define the problem and communicate among the dimensions and different objectives, has attracted much attention in recent years; thus, at the present study, the problem is defined as discrete. Accordingly, each of the project activities can be done in different ways, each of these methods has different cost, time and carbon dioxide emission, quality and total slack, and the target is to find an optimal set of procedures that optimize all these indicators in project execution, and meantime, time and cost of the project must not be more than the upper limit considered, and the quality of implementation of project must not be less than the lower limit considered.

The considered project includes n + 2 number of activities that are numbered from 0 to n + 1, which activities 0 and n + 1 are the dummy activities, respectively, indicate the beginning and end of the project. In addition, each project can be indicated with a network G = (V, E), where, V represents the nodes of project activities and E, indicates vectors, or the link between their activities (Assuming the network is indicated as an AON network). In addition, as mentioned before, any activity can be done in different methods as $r(i) \in k$, that each method k has different time (d_{ik}), cost (c_{ik}), quality (q_{ik}) and emission of carbon dioxide (e_{ik}). Assumptions and constraints taken into account in the study are listed below:

1. The problem is defined as discrete; **2.** The problem is considered as definitive; **3.** AON network of project activities is determined; **4.** The activities have FS relationship; **5.** Each activity begins after the end of all of its predecessors; **6.** All activities of project can be crashed; **7.** The objective functions considered in this study are: minimizing project duration, minimizing the cost of the project, maximizing project quality, minimizing dioxide emissions from the project and maximizing the plan robustness;

8. The project budget is limited; **9.** Total time to implement the project has the upper limit; **10.** For the quality of projects, the minimum amount is determined; **11.** Activities are not allowed to preempt;

12. There are r (i) different methods to carry out any activity; **13.** Choosing a method to carry out any activity, there is no possibility of changing the way to do it; **14.** To carry out any activity, more than one source can be used; **15.** For simplicity, the activity duration is intended as an integer; **16.** Weight of the quality of all activities of the project - to calculate the total quality - is taken into account equally;

17. Dioxide Carbon emissions, including direct emissions (due to electricity and diesel consumption of equipment during construction) and indirect emissions (from production and transportation of materials, consumable materials of the Project); **18.** The quality of each procedure is selected a number between 1 and 5 based on expert judgment; **19.** On how to perform an activity, the method with more time has less cost, but the quality may be lower or higher.

3-2-Research steps

In this research the following steps are used to solve the problem:

Step1: Presenting the mathematical model of the problem.

Step 2: Giving a developed version of genetic algorithm called Reference Group Genetic Algorithm (RGGA) to solve the problem.

Step 3: Generating a set of test problems to evaluate the performance of RGGA.

Step 4: Comparing the obtained result by RGGA and a Classical Genetic Algorithm (CGA).

In the next section the obtained results by implementing the research steps are mentioned.

4-Results

In this section the results of implementation of research steps are described.

4-1- Presenting the mathematical model

Before expressing the mathematical model, parameters and variables for the decision are presented as the following.

Table 2. Parameters and variables of model

Sets	
V	Set of activities
E	Set of arcs
Indices	
i, j	Index of activities
K	Index of execution modes
L	Index of parts activity parts
Parameters	
n	Number of real project activities
m	Total number of materials used in the project
0, n+1	Dummy starting and ending activities
C	Upper-bound of project cost
T	Upper-bound of project time (deadline)
Q	Lower-bound of project quality
r(i)	Number of execution modes for each activity
c_{ik}	Cost of activity i in mode k
q_{ik}	Quality of activity i in mode k
L_{ij}	Time lag between activity i and activity j
d_{ik}	Duration of activity i in mode k
$Q_{ed_{ik}}$	Electricity consumption of activity i in mode k in project site
$Q_{dd_{ik}}$	Diesel consumption of activity i in mode k in project site
$Q_{l_{ik}}$	Consumption of material l in activity i in mode k
$Q_{el_{ik}}$	Electricity consumption for transportation of material l for activity i in mode k
$Q_{dl_{ik}}$	Diesel consumption for transportation of material l for activity i in mode k
F_e	Carbon Emission Factor (CEF) per electricity unit consumption
F_d	Carbon Emission Factor (CEF) per diesel unit consumption
F_l	Carbon Emission Factor (CEF) per unit production of material l
NS_i	Total number of successors of activity i
TS_i	Total slack of activity i
Big	A real big positive number
Decision variables	
F_i	Finish time for activity i
S_i	Start time for activity i
x_{ik}	Binary decision variable: Equals to 1 if activity i is executed in mode k; and 0 otherwise

With regard to the assumptions and constraints taken into account, the model will be as follows:

$$\text{Min Time} = S_{n+1} \tag{1}$$

$$\text{Min Cost} = \sum_{i=1}^{n}\sum_{k=1}^{r(i)} x_{ik}c_{ik} \tag{2}$$

$$\text{Max Quality} = \sum_{i=1}^{n}\sum_{k=1}^{r(i)} x_{ik}q_{ik} \tag{3}$$

$$\text{Min } CO_2 \text{ Emission} = \sum_{i=1}^{n}\sum_{k=1}^{r(i)} x_{ik}(e_{d_{ik}} + e_{in_{ik}}) \tag{4}$$

$$\text{Max Robustness} = \sum_{i=1}^{n} NS_i \times TS_i \tag{5}$$

S.T.

$$\sum_{k=1}^{r(i)} x_{ik} = 1 \tag{6}$$

$$\sum_{i=1}^{n}\sum_{k=1}^{r(i)} x_{ik}c_{ik} \leq C \tag{7}$$

$$\sum_{i=1}^{n}\sum_{k=1}^{r(i)} x_{ik}q_{ik} \geq Q \tag{8}$$

$$S_{n+1} \leq T \tag{9}$$

$$F_i + L_{ij} \leq S_j \quad \forall i, j|\ j \text{ is successor of } i \tag{10}$$

$$S_0, F_0 = 0 \tag{11}$$

$$e_{d_{ik}} = Q_{ed_{ik}} \times F_e + Q_{dd_{ik}} \times F_d \tag{12}$$

$$e_{in_{ik}} = \sum_{l=1}^{m}\left(Q_{l_{ik}} \times F_l + Q_{el_{ik}} \times F_e + Q_{dl_{ik}} \times F_d\right) \tag{13}$$

$$S_i + d_{ik} \leq F_i + Big(1 + x_{ik}) \quad \forall i, j \tag{14}$$

$$TS_i \leq S_j - L_{ij} - F_i \quad \forall i, j|\ j \text{ is successor of } i \tag{15}$$

$$F_i, S_i, TS_i \geq 0 \quad \forall i \tag{16}$$

$x_{ik} \in \{0,1\} \qquad \forall i, k$

In this model, formulas 1 to 5, respectively, represent the objective functions of time, cost, quality, and dioxide emissions and the increase of plan robustness. The constraint 6 ensures that any activity is done only in one way. The constraints 7, 8 and 9, respectively, indicate budget constraints, minimum quality and deadline of the project. constraint 10 shows the relationship between the activities, and indicates that the project activities have FS relationship. Constraint 11 ensures that none of the activities of the project begin earlier than zero. Constraints 12 and 13 are used to calculate the direct and indirect dioxide each of activity methods. Constraint 14 links finish time and start time of each activity. Constraint 15 determines the total slack of each activity. Constraint 16 determines the type and sign of each variable.

Thus, as can be observed in the mathematical model, in this study, with a comprehensive view, the control of the important factors is discussed that should be considered by all project managers. This integrity can't be seen in any of the previous research in this area. It should be noted that, regardless of the quality of the project, can't enter the today's competition arena, and on the other hand, environmental problems and the contribution of construction projects in the creation of pollutants, has led project managers to pay more attention to environmental impacts of their projects in many developed countries, on the other hand, it should be noted that, without the development of robust and practical program, there will not be possible to accomplish the desired goals, and the project will not be prosperous; so, in this study, quality, the dioxide emission and also the robustness of plan is considered along with the time and cost of the project. In the next section, the solution for a modeled problem is presented. As mentioned above, the problem defined in this study is a multi-objective trade-off discrete problem and the decision variable in the model is way of doing activities. This problem is an NP-hard problem because increasing the number of different methods of activity, solution space of the problem, will increase exponentially. To solve such problems, the meta-heuristic algorithms are used. To solve the mathematical model defined, a new genetic algorithm is presented as RGGA. In which the role model theory in sociology on genetic algorithm has been implemented. More details about this algorithm are presented in the next section.

4-2- Reference Group Genetic Algorithm (RGGA)

Genetic algorithm already has been widely used in different fields, including optimization problems, scheduling, transportation, and artificial intelligence and so on. Looking at the trade-off problems defined in the field of control of construction projects, it can also be clearly seen that this algorithm is the most widely used algorithm (Nabipoor Afruzi et al., 2013).

4-2-1- Structure of algorithm

The proposed algorithm in the present study has a flowchart similar to that of the genetic algorithm, with the difference that, crossover and mutation operators in this algorithm are different from the normal genetic operators. In fact, the proposed algorithm is a genetic algorithm, which is improved inspired by the idea of an American sociologist, Robert King Merton. Merton believed that, individuals compare themselves with individual or group that has a position which they want or are interested in acquiring it (Holton, 2004). An example of these imitations is the imitation of people (especially young people) from artists, athletes, etc. So, this concept has been used for designing crossover and mutation operators in the proposed algorithm. In this algorithm, a set of *k* chromosome that has the best objective function value is considered in a set, as a set of good role models (RM) of society, and a list of k chromosome with the worst objective function value is considered as a set of bad role models of society. Chromosomes in the community are trying to make themselves look like good RM, and they are trying to be different from the bad RM. In the following sections, operators of mutation and crossover of RGGA algorithm are explained. Before explaining the crossover and mutation operators, similarity and dissimilarity procedures of chromosomes are described. Flowchart of RGGA is shown in figure 1.

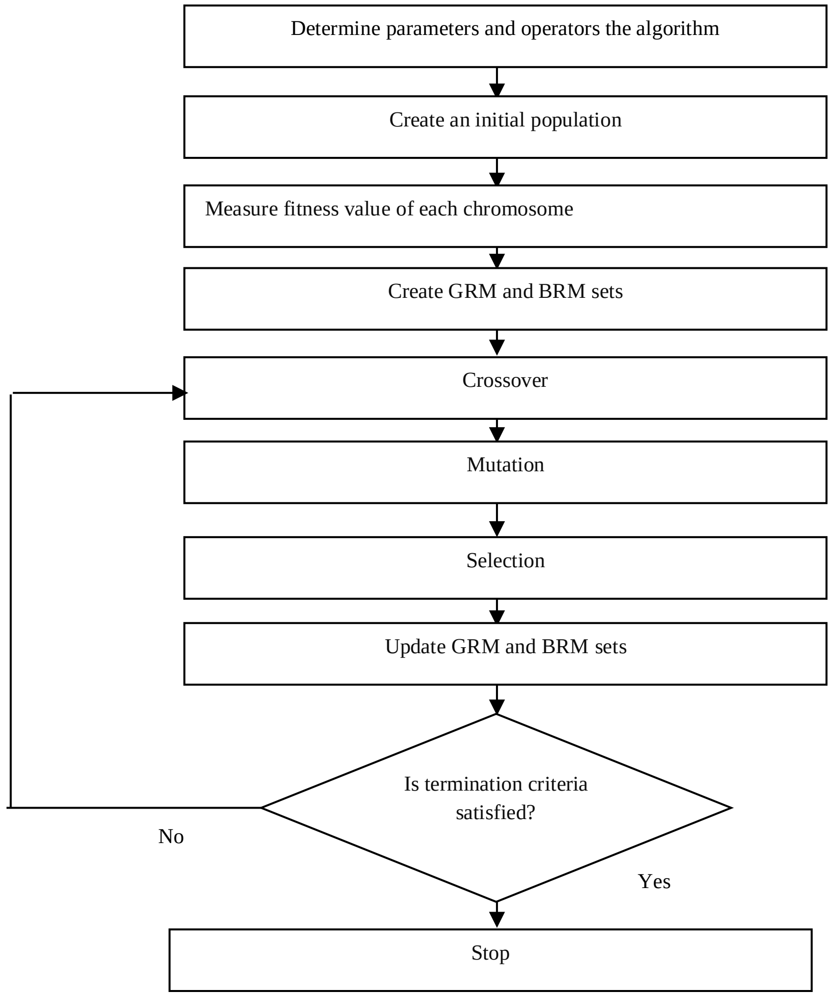

Fig 1. RGGA flowchart

Moreover, it should be noted that the structure of the chromosomes to solve the mathematical model proposed is like strings that the number of their genes is equal to the number of project activities the value of gene is equal to a method to perform each activity. An example of chromosome is shown in Figure 2. In this chromosome, it is assumed that there is a project with 10 activities, and there are 6 ways to perform each activity.

1	3	5	2	2	6	1	4	5	3

Fig 2. Chromosome (10 activities and 6 methods per activity)

4-2-2- Crossover and mutation

Before expression crossover and mutation operators in the RGGA, two processes known as similarity and dissimilarity procedures are expressed.

4-2-3- Similarity procedure

Similarity procedure is a process that occurs between two chromosomes. During this process one of the chromosomes plays as a role model and the other one plays as a receptor role. And with the implementation of this process, some properties of model are transmitted to acceptor chromosome. In this process, a gene (The method of Activity) of receptor chromosome is randomly selected. If the amount allocated to the receptor gene is different from the amount allocated to such gene on role model chromosome, the amount of receptor chromosome gene changes into the amount of gene on pattern chromosome. However, if the gene value on receptor chromosome is equal to the amount of such gene on RM chromosome, no change will be needed. The influence of the receptor chromosome may be different from RM chromosome. For this regard, a random number between zero and one is chosen for every time implementation of the simulation process and it will multiply the number of genes in the chromosome. The integer part of the resulting number is the number of times the simulation process must be repeated between selected chromosomes.

4-2-4- Dissimilarity procedure

This process, like the similarity process, occurs between two chromosomes. During this process one of the chromosomes plays as a role model and the other one plays as a receptor. And with the implementation of this process, some properties of model are transmitted to acceptor effect chromosome. In this process, a gene (The method of Activity) of receptor chromosome is randomly selected. If the value of the selected gene on receptor chromosome is equal to the gene value on pattern chromosome, then the gene value on receptor chromosome randomly changes to another authorized amount, but if the selected chromosome is different from its unique gene on role model chromosome, any changes will be needed. The effectiveness of receptor chromosome of RM chromosome, according to the simulation method is determined by a random number between zero and one. In the proposed algorithm in present study, similarity and dissimilarity processes have been used for the design and integration of mutation operators. These two operators are explained below.

4.2.5. Mutation operator

In every society, bad and good RMs can always be found and people are always trying to access the features of good RMs, and get away from the characteristics of bad RMs. Accordingly, the mutation operator is performed in two phases in the algorithm RGGA. In the first phase, a chromosome is selected randomly from the population as receptor chromosome and one chromosome is randomly selected from good RM set as pattern chromosome, and then the similarity process is performed for them (Figure 3). The number of mutation operator repetition is one of the RGGA algorithm parameters that are shown as Mute rate.

4.2.6. Crossover operator

Apart from models, people in a community may affect each other. This concept is used in crossover operator design of RGGA algorithm. Thus, the two chromosomes from the population are selected randomly (the roulette wheel is used for this regard), and one of them as a template and another to be considered as receptor chromosome, and similarity and dissimilarity processes are done for them (Figure 3). In this study, only the similarity process is used for applying the crossover operator. The number of crossover operator repetition is one of the RGGA algorithm parameters, and is shown as Cross-rate.

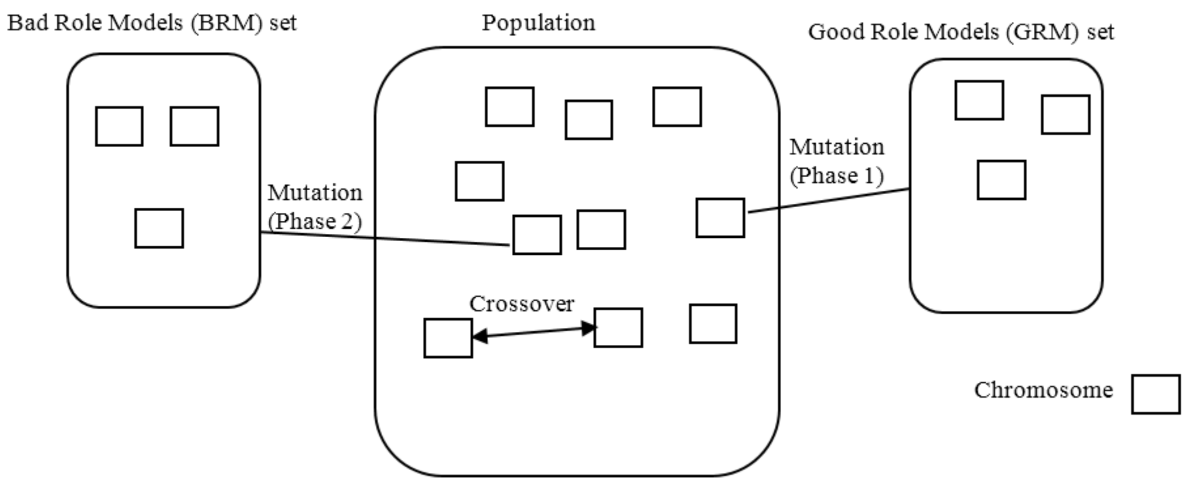

Fig 3. Structure of RGGA

4-2-7- Fitness function

Evaluation of chromosomes in generations takes place with the help of fitness function. Chromosome competence is measured based on their performance in the realization of the objective functions, so the fitness function, should be defined in relation to the objective functions. In this study, for providing the fitness function, the method provided by the Zhang and Xing (2010) , is used. According to the presented method, the fitness function is defined as follows.

$$Fitness = \sum_{o=1}^{O} w_o u_o \qquad F \in [0,1], u_o \in [0,1] \tag{16}$$

In this formula, O represents the number of objective functions, w_o, the weight of objective function and u_o represents the normalized objective function, where $\sum_{o=1}^{O} w_o = 1$. In this equation, the u_o for each of the objective functions considered is calculated as follows:

$$u_T = \frac{T^+ - T}{T^+ - T^-} \tag{17}$$

$$u_c = \frac{C^+ - C}{C^+ - C^-} \tag{18}$$

$$u_{CO2\ Emission} = \frac{E^+ - E}{E^+ - E^-} \tag{19}$$

$$u_Q = \frac{Q^+ - Q}{Q^+ - Q^-} \tag{20}$$

$$u_R = \frac{R^+ - R}{R^+ - R^-} \tag{21}$$

In the above equations, T^+, C^+, E^+, Q^+ and R^+, respectively, represents the maximum time, maximum cost, the maximum amount of dioxide emissions, maximum quality and maximum robustness of plan. And the values of T^-, C^-, E^-, Q^- and R^-, are minimum of the objective functions mentioned. If, however, the importance of each function to other functions is shown by assigning weights to each of the functions, the fitness function will be equal to the following formula:

$$Fitness = w_T u_T + w_C u_C + w_E u_E + w_Q u_Q + w_R u_R \tag{22}$$

As observed in the mathematical model provided for this problem, in this model, 5 objective functions should be optimized simultaneously, and whereas, the scale of the functions is different, with the help of the equations above, the value of objective functions are normalized, and all numbers have changed to numbers in the range between 0 and 1. Thus, the fitness function is a maximize function and is as follows:

$$\begin{aligned} Max\ fitness = {} & W_1(1 - Cost_{normalized}) + W_2(1 - duration_{normalized}) \\ & + W_3(1 - Emission_{normalized}) + W_4 Quality_{normalized} \\ & + W_5 Robustness_{normalized} \end{aligned} \tag{23}$$

Thus, total time, total cost, total carbon dioxide emissions, total quality and plan robustness for each chromosome is calculated and the resulting numbers, with the help of 17, 18, 19, 20 and 21 are normalized, and are used in relation to fitness function. To get the maximum and minimum values for each objective function in each problem, and put them in equations from 17 to 21, minimum and maximum values have been calculated by taking the worst and the best method for each of the parameters of time, cost, and quality dioxide emissions, to calculate the maximum and minimum weighted slack values, at first 1000 chromosomes randomly are chosen, and maximum slack is calculated for them, and the maximum and minimum of the objective is extracted of the 1000 solutions, and after each iteration of the algorithm, if the value obtained is greater than maximum or less than the minimum, it will be replaced by the previous value.

4-2-8- Selection operator

Selection of some chromosomes for next generation is done based on elitism, and accordingly, a fraction of the population with the highest fitness function directly is transferred to the next generation (it is shown by best and is one of the genetic algorithm parameters). Other chromosomes are selected using a roulette wheel, and crossover and mutation operators are applied on them.

4-2-9- Stop criteria

If the best fitness function of chromosomes in several successive generations does not improve, the algorithm ends. The number of consecutive iterations is defined by a parameter called termination. After numerous implementations and experimentally, it was found that levels of 60% and 30%, respectively, for cross rate and mute rate in the proposed algorithm leads to achieve better results. Also, the population of each generation (Pop size) and the elitism (best), respectively, was determined 100 chromosomes and 10%. The termination criterion for large and medium problems, 20 and for small issues, 10 was detected. Also, the number of members of each group of good and bad models, 5 members was determined. In the next section, the algorithm RGGA is used to solve problems, and to validate the proposed algorithm, the results of its application are compared with results from classical genetic algorithm.

4-3- Generating test problems

To evaluate the performance of RGGA, 81 problems with different sizes are created and these problems have been solved using a Classical Genetic Algorithm (CGA) and RGGA, and the results were compared with each other using them. All operators and parameters in CGA and RGGA is similar, except that GGA conventional swap mutation operator.

The problem studied has various parameters such as the number of activities, methods of doing each activity and the cost of the project activities. In order to create a diverse range of issues for each of these parameters, the levels of low, medium and high are considered. For number of active parameter, the values of 10, 30 and 50 are considered. For parameter of the number of methods performed for each activity, three values of 2, 4 and 6 modes, are considered. On the other hand, for parameter of the duration of doing any activity, three different modes are defined. In the first case, times randomly are selected from interval [1, 10]. In the second and third modes, respectively, they are selected from the time interval [10.40] and [40,100]. Similarly, for the costs of the activity, the three different ranges of [30,200], [300.2000] and [2000.7000] are used and the formula α* P is used for the parameter of upper limit for total time of implementation of the project. The P is obtained by the total processing time activities (in a way that has the most time for doing). 0.9 is also intended for α. Therefore, taking into account the different states for the number of project activities, the number of methods for doing activities, different intervals for the time of doing activities, as well as the cost of doing activities (3 * 3 * 3 * 3) 81 problems can be defined. For other parameters, only one mode has been considered. Value of direct emissions of carbon dioxide of activities is selected from the uniform distribution of 90,000 to 500,000 and the value of indirect carbon dioxide emissions is chosen from the Uniform distribution 200,000 to 700,000 (The expert judgment is used to determine these ranges). All coding using SQL Server 2012 T-SQL language is written in software, and with the help of a computer, Intel Core i7-4702MQ CPU @ 2.20 GHz is running.

4-4-Comparison of RGGA and CGA

In this section, the results of algorithms are examined. Comparisons have been carried out in six states. In the first case, all of the coefficients of 0.2 were considered. To create 5 other cases, one of the coefficients 0.4 and others 0.15 are considered. And 81 problems generated with the help of the 6 fitness functions, using classical genetic and RGGA algorithms have been solved, and the results are compared with each other. In the tables below, the average amount of competency, cost, time, quality, filtrating and CO2 emissions related to the ultimate solution of both algorithms is presented. Also, the number of times that RGGA had a greater solution than CGA (NBR), the number of times that both algorithms have presented the same solution (NER), and the number of times that RGGA was worse than CGA (NWR), is displayed. As shown in these tables, the results of the two algorithms, based on the number of project activities, and the number of procedures performed each activity have been partitioned to do a more accurate analysis of performance of the algorithms used.

Table 3. Results of implementing RGGA and CGA where W1=0.4, W2=W3=W4=W5=0.15

		Number of activities			**Number of methods per activity**			**Total**
		10	30	50	2	4	6	
Average of RGGA results	Fitness	0.740796	0.75744	0.769159	0.741494	0.750926	0.774976	0.755798
	Cost	13891.04	43149.11	72354.26	49415.93	42423.11	37555.37	43131.47
	CO_2	6628377	20810352	35165591	21517954	20805384	20280982	20868107
	Duration	202.4444	631.1111	1001.37	610.7778	617.4815	606.6667	611.6418
	Quality	35.55556	100.8889	171.8519	98.81481	102.1852	107.2963	102.7655
	Slack	136.7037	464.9259	734.7407	392.9259	461.8889	481.5556	445.4568
Average of CGA results	Fitness	0.741063	0.754681	0.767383	0.74167	0.749142	0.772316	0.754376
	Cost	13932.93	43464.74	72402.07	49459.7	42272.56	38067.48	43266.58
	CO_2	6653791	20790782	34950897	21465781	20779718	20149971	20798490
	Duration	202.9259	633.8148	1000.741	611.1481	618.6667	607.6667	612.4939
	Quality	35.92593	101.8519	170.5926	98.48148	103.8889	106	102.7901
	Slack	137.1852	466.4074	734.8148	395.5556	459.5185	483.3333	446.1358
NBR		9	10	14	3	12	18	33
NER		17	9	3	21	6	2	29
NWR		1	8	10	3	9	7	19

Table 4. Results of implementing RGGA and CGA where W2=0.4, W1=W3=W4=W5=0.15

		Number of activities			Number of methods per activity			Total
		10	30	50	2	4	6	
Average of RGGA results	Fitness	0.750734	0.755653	0.769034	0.746215	0.757473	0.771733	0.758474
	Cost	16739.52	52003	88619.85	55091.04	52655.67	49615.67	52454.12
	CO_2	5933542	18104231	30462320	19973575	17792048	16734470	18166698
	Duration	203.4815	634.2222	1010.333	618.7037	619.7778	609.5556	616.0122
	Quality	35.44444	98.55556	171.0741	98.74074	103.7407	102.5926	101.6914
	Slack	148.1481	463.6296	740.8889	403.1111	467.4815	482.0741	450.8889
Average of CGA results	Fitness	0.748364	0.75582	0.767381	0.746938	0.75636	0.768267	0.757188
	Cost	17121.11	51601.89	88186	54505.81	52968.85	49434.33	52303
	CO_2	5920434	18280266	30613917	20025913	17787679	17001025	18271539
	Duration	200.4444	627.2593	1014.074	618.4444	615.8148	607.5185	613.9259
	Quality	35.48148	99.18519	172.3704	99.37037	103	104.6667	102.3457
	Slack	143.7778	468.4074	740.1111	405.2222	466.7037	480.3704	450.7654
NBR		5	12	13	5	12	13	30
NER		17	5	3	17	5	3	25
NWR		5	10	11	5	10	11	26

Table 5. Results of implementing RGGA and CGA where W3=0.4, W1=W2=W4=W5=0.15

		Number of activities			**Number of methods per activity**			**Total**
		10	30	50	2	4	6	
Average of RGGA results	Fitness	0.709911	0.717979	0.725533	0.704377	0.714873	0.734174	0.717808
	Cost	16607.07	50711.3	86411.89	54748.78	51791.11	47190.37	51243.42
	CO_2	6534254	20442866	34409849	21320918	20228559	19837493	20462323
	Duration	169.0741	547.4444	901.9259	550.5556	544.3333	523.5556	539.4815
	Quality	36.40741	104.1111	176.4444	98.92593	107.8889	110.1481	105.6543
	Slack	101.3704	395.963	686.8148	312.2593	421	450.8889	394.7161
Average of CGA results	Fitness	0.708845	0.718152	0.727246	0.704128	0.716504	0.733611	0.718081
	Cost	16667.93	51088.89	85923.3	54722.37	51128.22	47829.52	51226.71
	CO_2	6535562	20494749	34443627	21300882	20313850	19859205	20491313
	Duration	169.3704	547.3333	902.6296	550.8519	542.9259	525.5556	539.7778
	Quality	36.33333	103.6296	175.2222	98.74074	106.0741	110.3704	105.0617
	Slack	102.3333	395.6667	690.3704	312.6296	425.7407	450	396.1235
NBR		5	7	12	4	8	12	24
NER		19	8	3	20	6	4	30
NWR		3	12	12	3	13	11	27

Table 6. Results of implementing RGGA and CGA where W4=0.4, W1=W2=W3=W5=0.15

		Number of activities			Number of methods per activity			Total
		10	30	50	2	4	6	
Average of RGGA results	Fitness	0.745977	0.765313	0.772826	0.743516	0.763026	0.777574	0.761372
	Cost	17145.85	52515.78	87338.52	54203.7	53383.63	49412.81	52333.38
	CO_2	6743144	20872627	35139158	21526980	20759908	20468041	20918310
	Duration	201.5926	628.963	1018.481	622.7407	621.1111	605.1852	616.3455
	Quality	42.03704	121.2593	204.5926	111.037	125.9259	130.9259	122.6296
	Slack	133.6667	466.2963	738.7037	400.0741	465.4815	473.1111	446.2222
Average of CGA results	Fitness	0.741373	0.764378	0.774767	0.744756	0.763158	0.772605	0.760173
	Cost	17127.96	52264.07	87683.33	54489.04	53133.74	49452.59	52358.45
	CO_2	6804751	20995015	35064641	21507432	20905051	20451923	20954802
	Duration	202.8148	632.1111	1013.704	621.7037	617.5556	609.3704	616.21
	Quality	42	122.037	205.1852	111.3704	127.1481	130.7037	123.0741
	Slack	135.2222	464.1481	738.037	400.2222	461.1111	476.0741	445.8024
NBR		8	11	12	3	12	16	31
NER		18	7	4	20	6	3	29
NWR		1	9	11	4	9	8	21

Table 7. Results of implementing RGGA and CGA where W5=0.4, W1=W2=W3=W4=0.15

		Number of activities			Number of methods per activity			Total
		10	30	50	2	4	6	
Average of RGGA results	Fitness	0.75751	0.799645	0.807842	0.769657	0.789056	0.806283	0.788332
	Cost	16585.07	48940.7	82368.59	52928.15	49936.52	45029.7	49298.12
	CO_2	6642932	19994569	33386923	20996405	19777727	19250293	20008141
	Duration	210.6296	614.5185	981.5185	621.3333	604.5556	580.7778	602.2222
	Quality	36	107.7037	181.4444	101.0741	111.8889	112.1852	108.3827
	Slack	177.0741	472.5926	746.963	428.6667	478.5926	489.3704	465.5432
Average of CGA results	Fitness	0.757357	0.79854	0.807604	0.770439	0.789519	0.803543	0.787834
	Cost	16766.3	48975.04	81634.52	52814.89	49897.07	44663.89	49125.29
	CO_2	6630835	20133221	33597378	21077204	19810410	19473821	20120478
	Duration	212.4815	615.3333	989.3704	619.5926	608.4815	589.1111	605.7284
	Quality	35.92593	108.3704	182.037	101.1852	110.2593	114.8889	108.7778
	Slack	178.4815	473.7407	749.5185	428.4815	479.8889	493.3704	467.2469
NBR		6	14	13	5	12	16	33
NER		12	5	0	14	3	0	17
NWR		9	8	14	8	12	11	31

Table 8. Results of implementing RGGA and CGA where W1=W2=W3=W4=W5=0.2

		Number of activities			Number of methods per activity			Total
		10	30	50	2	4	6	
Average of RGGA results	Fitness	0.70345	0.72186	0.74446	0.70177	0.71953	0.74847	0.723257
	Cost	16079.22	48556.37	81736.78	52473.22	49333.59	44565.56	48790.79
	CO_2	6383055	26664205	33289177	20978361	19633170	25724906	22112146
	Duration	197.2222	627.4444	985.6296	614.1852	607.5556	588.5556	603.4321
	Quality	37.74074	108.1852	184.7778	103.037	111.2963	116.3704	110.2346
	Slack	144.9259	509.2963	771.7407	413.0741	500.1111	512.7778	475.321
Average of CGA results	Fitness	0.70337	0.72216	0.74411	0.70208	0.71948	0.74808	0.723213
	Cost	16075.7	48970.48	83183.22	52804.93	50239.48	45185	49409.8
	CO_2	6379699	19904310	43392681	20961763	19748849	28966078	23225563
	Duration	198.2593	642.1481	981.8148	613.8889	608.7407	599.5926	607.4074
	Quality	37.85185	108.2963	183.9259	103.0741	111	116	110.0247
	Slack	145.6667	508.9259	769.4815	413.2963	498.2593	512.5185	474.6914
NBR		3	8	11	0	10	12	22
NER		23	12	7	25	12	5	42
NWR		1	7	9	2	5	10	17

As shown in tables 3 - 8, the solutions obtained by using the proposed algorithm for the big and small problems is better than medium. The NER indicator is declined by increasing the size of the problem. NBR and NWR indicators, by increasing the size of the problem has increased, and in most tables, with increasing the size of the problems, differences between NBR and NER has increased (NBR index is more in often partitions.). By analyzing all the results in Tables, it is concluded that in 35% of the problems, the solutions obtained are equal and in 36% of cases, the algorithm RGGA has achieved better solutions; however, meanwhile, the results obtained using the algorithm GA, in 29% of cases have been better. The average best solutions obtained for each 5 objective function average of 81 problems examined using two algorithms is given in the table. The results show that the algorithm proposed in this study, in total, compared to CGA had better performance.

5- Conclusion

In recent years, researchers have stated that, in addition to time and cost, the quality of projects must also be considered, and studies conducted on earlier studies indicate that the number of studies that examine the increase of the quality while reducing the time and cost of the project is increasing, in this study, in addition to time and cost, the quality is evaluated as an objective function. But it should be noted that, decision-makers, as well as are unaware of or ignore the environmental impacts of their projects. But, in recent years, the construction industry has been charged to create a wide range of environmental problems, including excessive use of the world's resources, and polluting the environment, and the production of greenhouse gases, and in the meantime, carbon dioxide is the main gas generated in the production of building materials. Thus, according to the adverse effects of the project on environmental degradation, and given the need to reduce greenhouse gases and combat global warming, this research is focused on the production of carbon dioxide in the construction industry. Thus, in this study, in addition to the time, cost and quality, reducing carbon dioxide emissions from the project is also considered and is examined as a fourth function. The preemption in project implementation is inevitable (in practice). There are many factors that can lead to temporary preemption of the project. It should be noted that, lack of attention to the possibility of termination during implementation of a project can lead to a delay in its completion and tardiness. So, for development of an actual plan, the possible preemption in the early stages of planning must be addressed, and on the other hand, the greater slack of project activities is associated with the greater possibility of preemption (without affection on total project duration). Thus, in present study, in addition to four objective functions presented, as well as the robustness of plan is considered as fifth objective function. Whatever the schedule developed for the project has less directions or critical activities, the ability to preemption and avoid delays in the completion of the project will be higher, and it should be noted that, being critical or non-critical activity is determined due to its slack. Accordingly, a measure of the plan robustness developed is the weighted slack, which is the weighted sum of the total slack of all project activities; the weight considered in this manner for each activity is equal to the total number of all successors of the desired activity. So in present research, by studying published papers in the field of trade-off to control construction projects and other related issues, with a comprehensive view, the control of important factors that all project managers must consider them is discussed. To solve the problem defined in the study, a new approach, known as RGGA is presented. And to evaluate the performance of the proposed algorithm, 81 examples of problems, using classic genetic algorithm and proposed algorithm is solved and the results are compared with each other. Looking at the trade-off problems defined in the field of construction projects control, shows that genetic algorithm is the most widely used algorithms that have been used. The proposed algorithm in present study has a flowchart similar to the genetic algorithm flowchart, with the difference that, crossover and mutation operators in it are different from the normal genetic operators. In fact, the proposed algorithm is a genetic algorithm, which is improved inspired by the sociology theory of an American sociologist, Robert King Merton. By analyzing all the results for all 81 problems studied, the results show that the algorithm presented in this study, overall, compared to conventional genetic algorithm has better performance. In this study, on the one hand, a comprehensive model for solving trade-off problems is provided, and on the other hand, using a sociological theory, a new approach is presented to solving this problem. In this study, the problem conditions are considered as definitive, and on the other hand, only the value of weighted slack is intended as strengthening program developed. So, as field of research in the future, the following cases can be offered: Study of the problem in uncertain conditions, considering the possibility of preemption in the activities and prediction of more accurately the effect of preemption at different times, finding new algorithms to improve solutions for trade-off problems, comparing the two algorithms used in this study for other optimization problems.

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