Genetic Algorithm: An Innovative Technique for Optimizing a Construction Project

Paromik Ray, Dillip Kumar Bera, and Ashoke Kumar Rath

Abstract Time and cost are two basic objectives of any construction project. Optimization of these objectives is the main concern over the last three decades by the construction sectors. Many innovative techniques have been used by the construction companies to optimize the cost and time of a project. Genetic Algorithm (GA) method is one of the most advanced and widely used non-traditional search algorithms based on the mechanics of natural selection and natural genetics. The principle of natural selection is based on the "survival of the fittest" concept coined by Charles Darwin. It is neither an intelligent nor a smart algorithm but it searches for optimal solution in the solution space. The objective is to review GA as an optimizing technique used to generate high-quality solution for optimization process. Reproduction in GA is done by three sophisticated operators—selection, crossover and mutation through which optimal solution is found out only if the condition is true. Hence, GA method is useful optimization process in construction projects. The main advantage present in GA is providing more effective and efficient optimum value in a construction project. Moreover, it also provides optimal trade-off values between project duration and total work done. This concludes that GA can be widely used as an advanced innovative technique for optimization process in future construction project.

Keywords Time and cost · Genetic algorithm · Optimization process · Optimal trade-off · Construction project

P. Ray (✉) · D. K. Bera (✉) · A. K. Rath
School of Civil Engineering, KIIT Deemed to Be University, Bhubaneswar, India
e-mail: paromikray@gmail.com

D. K. Bera
e-mail: dkbera.fce@kiit.ac.in

A. K. Rath
e-mail: akrathfce@kiit.ac.in

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1 Introduction

According to the driven conditions of today's market, the construction industries are on the rise. All the construction companies including government and private sectors face a number of challenges during the period of construction. The main difficulties that fall during construction time of the project are the scheduled completion of project in the stipulated duration along with completion within the estimated budget of the project. The main parameters that a construction company mainly focuses on are the time and cost of a particular construction project. Also, at the duration of construction, other factors also come into consideration in the form of unpredictable factors, namely, labour performance, economical and social issues, execution errors of contractors, labour strike, design errors, labour strike, climatic changes, etc. These named factors are the majority which is responsible for the delay in the schedule of the project along with the increase in the budget of the project ultimately leading to the excess in the cost liabilities that get added to the budget of the construction project. The problems occurring in the construction site related to these factors are referred to as the Time–Cost Trade-off Problems (TCTO). For overcoming these particular situations that arise in the project, a step is being taken by the project planners and researchers for encountering this problem to process a perfect solution for optimization of TCTO-related problems in a construction project. This resulted in the development of various innovative optimization techniques of TCTO problems in a project site.

Advanced Neural Network (ANN) method, Line of Balance (LOB) method, Discounted Cash Flow (DCF) method, maximum flow–minimal cut theory method, Modified Adaptive Weight Approach (MAWA) method, critical path method and Genetic Algorithm (GA) method are some of the advanced, innovative and widely used techniques or methods which is mainly used for generating the maximum optimized solution of time and cost parameters of a complex and large construction project. The main objective of the review paper is to highlight the Genetic Algorithm (GA) method as the most used, easiest, efficient optimization method or technique in recent times for optimizing TCTO problems. Moreover, a summary or a brief overview of the various innovative techniques along with the recent works done by the researchers in the field of optimization of TCTO problems by using genetic algorithm method. Further, it is concluded that a review is done on the genetic algorithm method being the most efficient optimization technique for solving TCTO problems for future projects and works.

1.1 Brief Classification of Innovative Techniques

The table mentioned below (Table 1) highlights the various recent innovative techniques of optimization of time and cost in a project. The methods or techniques are

Table 1 Classification of different optimization techniques

Manual methods	Mathematical technique	Metaheuristic approach	Others
Different optimization methods			
• Maximum Flow Minimal Cut Theory (MFMC) • Least-Cost Scheduling Model • Chance-Constraint Programming Model • Line of Balance Method (LOB)	• Non-Linear Programming (NLP) • Linear Programming (LP) • Integer Programming (IP) • Dynamic Programming (DP) • Inventory Models • Stochastic Models • Simulation Model	• Evolutionary Algorithm (EA) I. Particle Swarm Optimization (PSO) II. Ant Colony Optimization(ACO) III. Modified Shuffled frog Leaping (SFL) • Genetic Algorithm(GA) • Genetic Programming(GP)	• Artificial Neural Network (ANN) • Discounted Cash Flow Method (DCF)

being derived from the previous works of the researchers and scholars who applied the process for optimization.

2 Optimization Process

Optimization is commonly defined as the process of finding the minimum/maximum values with reference to the main derivative or the objective function for satisfying the particular constraints of a function specified within a certain set of function. The main objective or goal of the optimization process is to process the correct or best set of solution of a mathematical solution of a TCTO problem. The main dependent of TCTO (Time–Cost Trade-off) problems is the critical path method of optimization process. Moreover, in a construction project, the duration of the project is the most important parameter for completion in the stipulated time. Also, the increase in scheduled time, increase in cost, unavailability of resources, the presence of risks, and quality and quantity of the materials occurring in the construction project are the main reasons for the requirement of optimization process. The method of Genetic Algorithm (GA) is the most widely, effective and efficient technique for the optimization process. Lastly, many scholars and researchers opted for the method of Genetic Algorithm (GA) as the prime method for optimization of TCTO problems.

3 Genetic Algorithm: An Innovative Technique for Optimization

The method of genetic algorithm belongs to the heuristic group of optimization which is itself an advanced optimization technique of solving TCTO problems in a construction project. This method is a non-traditional search algorithm for solving

both single-objective and multi-objective optimizations of TCTO problems depending on the natural algorithm and natural evolution process. This method was first proposed by the scientist named Charles Darwin on the theory of "survival of the fittest". Similarly, the method of Genetic Algorithm (GA) is neither a smart nor an intelligent algorithm which clearly indicates that the method is completely algorithm and mathematical based used for optimization of TCTO problems in a construction project [1]. This method consists of four main operations. At each of the following steps of the genetic algorithm method, these steps select the collected data as the values in a random manner. Further, the process of iteration takes place in generating an optimal solution to a TCTO problem. Moreover, the method of genetic algorithm is also dependent on the process of natural evolution. The optimized solution can be taken as an accurate solution because of the optimization process. The so-called accurate optimized solution obtained by the GA method is completely dependent on the total number of populations and on the fitness level objective function [2]. The method of GA has four main processes, namely, in a sequential order: initialization, selection, crossover and mutation.

Initialization: This process is mainly for the initialization of the collected data values to the fitness value objective function.
Selection: This process is mainly for the selection of the optimized solution values in a random manner. Commonly, this process is referred to as the random selection process.
Crossover: This process is mainly used at the time of interchanging the random values' position for generating the higher and correct optimized solution. This process is generating higher optimized values of a TCTO problem.
Mutation: This process is mainly used for flipping or swapping of more than one single value of the collected data values for generating a highly correct optimized solution of a TCTO problem [3] (Fig. 1).

The above flowchart is representing the main working principle of the optimization process using genetic algorithm method of a TCTO problem in a construction industry. As mentioned above, the flowchart also highlights the four main processes used for optimization process.

4 Working Process of Genetic Algorithm

The Genetic Algorithm (GA) method consists of four main processes, which generates the output of the optimized values of the TCTO problem of a construction project.

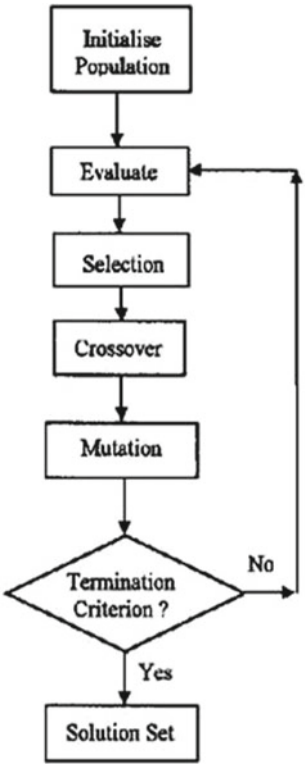

Fig. 1 Flowchart of genetic algorithm method

4.1 Initialization Process

Initially, at the starting of any genetic algorithm optimization process of any mathematical problem, a single variable is being assigned from any previous coded domain or a set. Initially, this easy step of initialization process using genetic algorithm method was found insufficient by many researchers and scholars. Furthermore, it is thought that the process lacked few specific other variables for optimization of TCTO problems [4]. However, more technology and research work lead to the innovation of the optimization technique of the method. Therefore, with the incoming of new technologies and modified parameters in use, it is now very reasonable to quote the initialization process which is one of the important processes for optimization of TCTO problems [5].

4.2 Selection Process

The main selection or the process of improvement of the fitness derivative function of the main chromosomes of the population can be achieved by the process of selection. The selection process is so-called dominating process of genetic algorithm method as it possesses the ability to change the fitness value function of an optimization problem [6]. In this process, the parents are being selected from their group of chromosome population of the data collected. The process of selection of the genetic algorithm method is performed in such a way that the chromosomes having a higher fitness value are having a maximum probability to be selected as the main parents of the fitness value function to be used in the optimization process [6].

The conclusion is that some of the population of the chromosomes of the collected data for optimization problem may contain some of the high-value fitness derivative function than the original derivative function which is the main formula for creating individual chromosomes for the optimization process of a TCTO problem. Ultimately, this process possesses a limitation of a lack of population diversity which leads to a lag in search algorithms in optimization process [7].

4.3 Crossover Process

After the completion of both the processes, initialization and selection processes, the third process is the crossover process. In this process, the derivative function parameters used in the genetic algorithm method create possible two chromosomes in this process. These parameters of the GA method use a random generator function for maintaining the two sets of functions of the domain or a set for the optimization process. This results in the formation of two chromosomes in the optimization process [8]. After the completion of the crossover process, the new set of chromosomes is being added to the set of previous chromosomes set to form a new population.

4.4 Mutation Process

The final process of the genetic algorithm is the mutation process. The main function of the process includes the increasing population diversity of the chromosomes. This process also includes the selection of the inner particles of chromosomes called genes in a random selection manner and then assigning those selected values within the corresponding intervals of pre-defined variables of selected set or domain [9]. That chromosome which follows the method of mutation contains a correct genetic code. The process of mutation enables these created genetic codes that are kept intact and do not get destroyed. Moreover, a non-uniform mutation can also be applied for the optimization process of a TCTO problem which leads to the shortening or

narrowing of the chromosomes population created for the optimization process of TCTO problem [10].

5 Use of Genetic Algorithm in Construction Industries

In a construction industry, the use of genetic algorithm for optimization of cost and time or any other parameter will be a valuable reference for the company, as it provides correct optimization values of cost and time, especially in a TCTO problem. Genetic Algorithm (GA) method in a construction industry acts as a useful option for optimizing, controlling, planning and scheduling of all the constructing activities mainly present in the project. It is referred to as a search algorithm containing the tools required for optimization used mainly for assisting the activity makers, planners, or designers in the company in order to achieve and generate a near-optimized solution of a particular TCTO problem. This method theory is extracted from the theory of evolution depending on the theory "survival of the fittest" that is applicable in the construction industry where the construction industry selects the specific and main activities required for construction work [11]. Similarly as mentioned earlier about the mechanisms or processes of GA method, it is the same applicable to construction industries. The method includes the main three processes even in the field of construction industry: (I) The initialization method which is mainly used for generating a set of initial data of total duration of a particular activity along with the total cost budget of that activity; (II) selection process that is mainly used for calculation and selection of the total collected data of the time and cost of the activities along with other parameters including quality, risk factors, material quantity, etc.; and (III) crossover process mainly used for processing and generating an improvement of the selected data containing the time and cost of the activities for a certain period of time [12]. These three main processes are very much applicable for optimization of TCTO problem at a construction industry.

5.1 Multi-objective Genetic Algorithm

The optimization of TCTO problem using genetic algorithm method is often referred as multi-objective genetic algorithm method, with single-objective genetic algorithm optimization being referred for single-objective functions especially total time or total budget cost of the project [13]. Moreover, many technologies have evolved over the past decades or in the past generation for the optimization of more than one objective function using GA method. Hence, the concept of multi-objective genetic algorithm came into the world and helpful for solving TCTO problems in a construction industry. With every advanced technology of the GA method along with effective and efficient process of optimization of the TCTO problems, slowly the popularity has been gained and in the coming years, the preference of multi-objective

genetic algorithm is higher. Clearly, for multi-objective genetic algorithm function, the optimization of fitness value definite function contains two different parameters containing two different optimum functions for optimization process. The multi-objective GA method does not possess or generate any superior or complex function as an optimizing output but generates a simple variable mathematical function which is very clear as an objective of the TCTO problem for optimization [14]. Thus, multi-objective genetic algorithm method is the most efficient and effective optimization technique for solving TCTO problems.

6 Case-Study: A Live Construction Project

The case study includes a live on-going construction project named "Bose Institute Construction Project" located at the city of Kolkata, West Bengal, India. The construction project includes the construction of G+15-storied educational or an institutional building that is situated in the main town of Salt Lake City of Rajarhat district in the city of Kolkata. The project consists of full-furnished construction of a 15-storied building along with the formation of the basement. The main work of the construction project consists of the main educational building of 15-storied along with two-side building consisting of 5-storied floor each. The main features and the requirement of the construction project are as follows:

Maintaining and ensuring the life-time structural ability of the educational building being constructed for duration of 15 years.

Ensuring proper and efficient construction of 15-storied educational building along with the two buildings of 5-storied each of the construction projects.

Decrease in the negative effects created in the environment and construction of an eco-friendly building structure making positive impact in the environment [15].

As per the construction point of view of the project, there are present around 65–70 activities throughout the project. It is quite difficult and near impossible for optimization of all the activities using genetic algorithm method. It has been advised to select a section or a separate small plan of the construction project for optimization using genetic algorithm method. Thus, for this review paper, a particular section of the construction project has been selected for the optimization using GA method.

6.1 Selection of the Activities

The selected activities for the optimization using GA method consist of the main important 10–12 activities from the part of ground floor of the building to the plinth level of the first floor of the on-going construction project. Other parameters are also included in a tabular form consisting of the duration and the estimated cost of the particular activity selected. The requirement of the cost and duration is much more important for the optimization process using GA method creating a more positive

Table 2 List of activities, duration, cost (I)

Activities	Original duration (Days)	Value of the activity
A. Reinforcement work of column	3	1,09,145
B. Column shuttering work	3	33,750
C. Column concreting work	4	90,813.25
D. Column de-shuttering work	4	7,057.50
E. Staging and shuttering work of beam and slab	3	36,572.60
F. Fabricating, placing and fixing of beam and slab	4	2,44,658

Table 3 List of activities, duration, cost (II)

Activities	Original duration (Days)	Value of the activity
G. Concreting work at ground floor with roof slab	3	1,71,270
H. Curing process	14	2,60,134
I. Removal of shutter staging materials	2	1,48,648
J. Brickwork (main floor along with partition wall)	4	2,60,734

impact and efficiency in the process [16]. The selected activities along with the duration and time are given below (Tables 2 and 3).

6.2 Deriving the Fitness Function

This particular construction project consists of the applications of the TCTO problem for optimization process. The derivative function will comprise the main parameters including the total duration and the estimated cost of all the activities [17]. The derivative function includes the optimization of the case study of a TCTO problem:

$$C = \mathrm{dc} + \mathrm{ic} - (\mathrm{id} - q)\mathrm{ie} + \sum_{\forall y} (\mathrm{nd}(y) - \mathrm{pop}(x, y))\mathrm{cs}(y) \tag{1}$$

where C = Total Cost; dc = Direct Cost; ic = indirect Cost = i.e. X id; id = initial duration of the network or duration of the network with normal cost; q = duration of the network after change in duration of the activity; i.e. = indirect expenses per day; nd = normal duration of the activity; pop = matrix of randomly generated durations as per our boundary conditions; cs = cost slope of the activities; x = population index; y = activity whose duration is being changed [15, 18].

The result obtained using the MATLAB 2018 software and a clear comparison of the result obtained is also being reviewed in the paper highlighting the importance of using genetic algorithm method for optimization process. By using the MATLAB 2018 software, an efficient and a clear comparison of the two outputs is obtained with the aid of bar graphs that are being generated from the software. With the help of bar chart generated, it becomes quite easy for processing the optimized solution of the problem [19]. In the bar chart generated, the cost timeline is being.

7 Discussion

The discussion is mainly about the comparison of the two main optimized outputs or results that are obtained by the optimization process using Genetic Algorithm (GA) method. From the above model or the graph shown below, it can be discussed that the optimized value or the output obtained is a satisfactory one. The proposed output or the optimized output obtained for the construction project using Genetic Algorithm (GA) is able to achieve an increase in (10–20)% than the estimated data available for the project. As per the output obtained and by verifying the output with the attached graphs and MATLAB software, the total duration of the optimized result showed an increase in 10%, whereas the total estimated budget of the construction project showed an increase in 20% of the estimated data collected. The optimized output showed a great percent of similarity with the estimated data collected from the construction sector or industry, but it is obvious that the increase in cost and time of the project is beneficial for the completion of project. The difference may arise for the reason of not more than 4–5 activities, which is the main reason for the increase in the estimated cost and total duration of the project.

8 Conclusion

It is concluded that the obtained results are being satisfactory. The objective of the construction involving a TCTO problem was a multi-objective genetic algorithm. Even the single-objective TCTO problem of a construction project also provided correct and satisfactory optimized results of cost and time using genetic algorithm method comprising of using high technology optimized algorithms and other rapidly developed formulas comprising algorithms for processing the optimized result of cost and time of a TCTO problem. The increase in the development of the multi-objective optimization problem using genetic algorithm method is on a major high demand as it also possesses a feature of comparison of two on-going construction projects, thus highlighting the superiority and domination of the genetic algorithm functions on the optimization on TCTO problems. As it is clearly shown in the above case studies, an increase in 10% of the optimized results obtained than the collected data of the construction projects. The estimated cost of the construction project is around 400

crores INR along with the estimated duration of the construction project for 5 years. By optimizing the selected data collected from the companies' file, the total estimated duration has come around in a span of 4 years, but with an increase of the cost of the project as it is known that both the parameters are independent of each other. It can be still debated whether using genetic algorithm method for optimization is the perfect choice in the future or not, but as per reports and concentrating on the comparison of the results obtained, GA method is an effective and efficient method for optimization process of TCTO problem. It is easily used and less laborious method as compared to the various innovative optimization techniques used. Upon the requirements of the planners or the designers of the construction project, the genetic algorithm method can be used as a better option for optimization of TCTO problems.

Obviously, taking into considerations the experience possessed by the researchers and the planners for the optimization process, genetic algorithm might lack the extra edge of being used in a TCTO problem because of the various advanced innovative techniques that is being used in construction projects for optimization process [14]. Moreover, the assurance of the quality of the work is also a major highlight of the construction project, and it is mainly dependent on the work experience of the planners and the designers involved in it. The use of genetic algorithm method for such a particular scenario is completely dependent on the different subjectivity processes of the project along with different advanced characteristics of the operator being used for the project. However, the main intention lies in providing the proper method of quality assurance of the work done along with generation of total innovative quality of work done in the project [13]. It is thus concluded from the comparison of the case studies that GA method is one of the innovative techniques for optimization of TCTO problem of a construction project. The following features are proofs of the advancement of the genetic algorithm.

- Genetic algorithm method works with the process of coding a parameter set, not with a particular parameter.
- Genetic algorithm method searches the main population of the chromosomes rather than a particular population of the chromosomes mainly for global exploration of the project purposes.
- Genetic algorithm method mainly uses the objective function or the derivative function rather than using any complex functions or integers for optimization purpose.
- Genetic algorithm method can use a random choice function for the mechanism for the optimization process acting as a guide for searching the specific algorithm for the improvement and advancement of the derivative or the fitness function.
- Genetic algorithm method also improves the process of easy and simple experimentation for different scenarios of the optimization problem.

The various features act as an aid for the researchers and scholars for using genetic algorithm method for optimization of any type of problem.

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