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Subcontractor selection using genetic algorithm

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Abstract

In the construction industry, subcontracting is a very common practice. Nowadays, most of the general contractors tend to sublet the large portions of construction works to subcontractors and they only act as construction management agencies. In other words, while subcontractors carry out the actual production work, general contractors organize and coordinate the subcontractors and control their works in terms of time, cost and quality. In the construction industry, since the general contractors are responsible to the owners for the works carried out by the subcontractors, the general contractors should select the most appropriate subcontractors for the work packages that constitute the entire project. In the literature, there are a great number of studies that focus on subcontractor selection practices in the construction industry. These studies can mainly be categorized into two groups, which are; 1) the studies that aim to identify the subcontractor selection criteria and their importance levels, and 2) the studies that aim to propose tools, techniques and/or methodologies for subcontractor selection. The common point of the studies in the second category is that they all focus on selecting the most appropriate subcontractor for one work package in the project. For instance, if the case is the airport construction project, the construction of car park may be one work package. In this study, selection of subcontractors for the all work packages in a construction project is made using genetic algorithm technique considering time, cost and quality performances. A real-life construction project is selected as a case study and the actual data regarding alternative subcontractors are collected. The subcontractors for all work packages were selected successfully using the genetic algorithm technique.

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Keywords: case study; genetic algorithms; subcontractor selection; time-cost-quality trade-off

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1. Introduction

Nowadays, most of the general contractors tend to sublet the large portions of construction works to subcontractors, and they only act as construction management agencies [1-6]. In other terms, they just control and coordinate the works of subcontractors and are responsible for site organization. In construction projects, especially in building projects, approximately 90% of the construction work is carried out by subcontractors [7]. There are several reasons behind this high level of subcontracting, which are; (1) complexity of the construction projects, (2) need for expertise in certain work packages, (3) need for skilled labor to carry out several construction activities, (4) need for specialized equipment, (5) utilization of specialized subcontractors for shortening time, increasing quality and decreasing cost, (6) solving cash flow and project financing problems, and (7) sharing risks with subcontractors to protect themselves from uncertainties and unstable conditions of the market [8-11]. Even though actual production works are performed by subcontractors, the general contractor is fully responsible for the works of the subcontractors to the owner.

Since the success of a general contractor in a construction project mainly depends on the performances of the subcontractors [15], selecting the right subcontractor for the right job is critical for not only for the successful completion of the project in question but also for the reputation and business continuity of the general contractor [2,10,14,16,17]. In the literature, there are a great number of studies that focus on subcontractor selection practices in the construction industry. These studies can mainly be categorized into two groups, which are; 1) the studies that aim to identify the subcontractor selection criteria and their importance levels [e.g., 1,2,5,10,11,14,17], and 2) the studies that aim to propose tools, techniques and/or methodologies for subcontractor selection [e.g., 2,12,13].

The common point of the studies in the second category is that they all focus on selecting the most appropriate subcontractor for one work package in the project. However, in real life, general contractors usually divide construction projects into major work packages and sublet most/all of these work packages to the subcontractors, who are selected through bidding or negotiation. Since the overall performance of the project is directly affected by the performances of the subcontractors, who undertake different work packages in the construction project, the interactions between all subcontractors should be considered during the subcontractor selection process. There are only limited studies [18,19], which consider the subcontractor selection process as a whole and take into account the interactions between the subcontractors, who are in charge of carrying out different work packages in the project, during the subcontractor selection process.

The main objective of this study is to develop a multi objective optimization model to assist general contractors in selecting the most appropriate subcontractors for all work packages based on time-cost-quality performances using the genetic algorithm. The proposed model enables general contractors to select the optimal subcontractor combination for all work packages by considering the interactions between the subcontractors and their impacts on the overall project performance in terms of time, cost and quality.

2. Research Methodology

2.1. Genetic Algorithms

Genetic algorithm (GA) was first developed by John Holland in the early 1970s [20,21]. It starts with creating an initial population, which represents a set of solution for the problem and uses a process similar to biological evolution for improving initial solutions [22]. Each individual represents a candidate solution in the form of a string called chromosome, and each chromosome consists of genes, which contain a set of values of decision variables (see Figure 1). The most important operators of GA are crossover and mutation. Crossover and mutaion operators are used for natural selection. These operators predominantly affect the performance of GA. These operators have different types and implementation styles based on the type of the encoding and the nature of the problem in question [23]. Crossover is used to create a new offspring from parent chromosomes. The crossover point is usually selected randomly, then the beginning of the new offspring chromosome is taken from the first parent and the rest is copied from the other parent (see Figure 1). Mutation operator is applied to provide randomness to the search at the gene level. Mutation randomly changes the specified gene of the new offspring (see Figure 1). In GA, mutation and crossover operators are repeated several times to produce the best chromosomes, which dominate the population.

The performances of the chromosomes are measured with the fitness function of the problem in question.

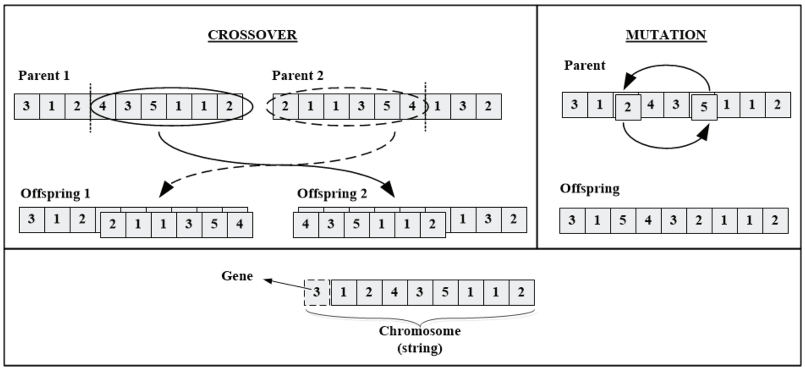

Fig. 1. Crossover and mutation processes in GA.

There are four main steps in GA: (1) creating an initial population, (2) selecting the best individual based on the fitness function of the optimization problem, (3) applying crossover to generate new individuals for the next generation, and (4) utilizing mutation on the new individuals to obtain diversification in the next generation [24]. Figure 2 shows the main steps of GA.

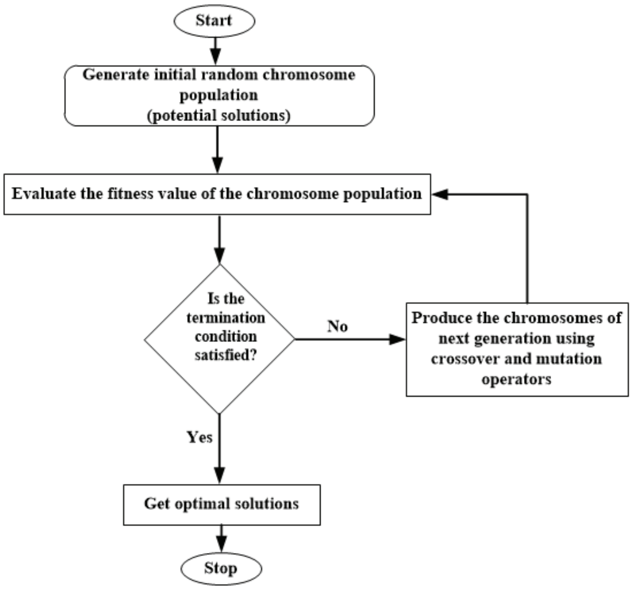

Fig. 2. Flowchart of GA.

GA uses some control parameters to run the algorithm. The control parameters of genetic algorithm were studied by several researchers using with different test problems (See Table 1).

Table 1. Proposed control parameter values for genetic algorithm.

Control Parameter	De Jong [25]	Schaffer [26]	Grefenstette [27]
Population Size	50-100	20-30	30
Crossover Rate	0.60	0.75-0.95	0.95
Mutation Rate	0.001	0.005-0.01	0.01

In the literature, several GAs, e.g., Vector Evaluated Genetic Algorithms (VEGA), Weighted Based Genetic Algorithm (WBGA), Niched Pareto Genetic Algorithm (NPGA), and Non-dominated Sorting Genetic Algorithm (NSGA), have been developed to solve multi objective optimization problems. First, Schaffer [26] introduced VEGA to find non dominated solutions, which constitute Pareto-Front. Then, the other versions of GAs (i.e., respectively WBGA, NPGA, PESA and NSGA), were generated to solve different type of optimization problems and to overcome the limitations of the older versions [24]. These new versions of GA have been designed to obtain different Pareto optimal solutions and to identify alternative solutions lying on or near to the Pareto-Front [30]. Among these versions, NSGA is the most commonly used algorithm [24]. However, NSGA has some limitations and then NSGA-II has been developed to overcome these limitations. Now, this algorithm is capable of achieving optimal solutions much closer to the Pareto-Front and also finding diverse solutions spread over the non-dominated front [30].

In this study, NSGA-II algorithm is used to provide general contractors with non-dominated optimal solutions from which they can select the best compromise solution based on the objectives of the construction project in question.

2.2. Case Study

This study deals with subcontractor selection problem of a trade center project, which was built in Samandira, Istanbul, Turkey in 2014. The owner of the project is one of the largest healthcare groups doing business in Turkey. The estimated construction cost was *15,869,770.00* TL, the total construction area was *2,000* m^2, the anticipated duration for the project was *500* days, and the contract type was turn-key. The owner of the project gave permission for using the actual data of the case study in this research. The general contractor of the studied project divided the tasks into 20 main work packages (i.e., *A*,…,*U*) and aimed to sublet all these work packages to subcontractors. The predecessor and successor relationships between these work packages are presented in the network diagram in Figure 2. In the studied project, the general contractor evaluated the subcontractors in terms of their cost, time and quality performances. The general contractor requested bid submittals from three subcontractor candidates (i.e., *Option_j*) for each work package. The bid submittals included the duration and bid price offered for the work package. The general contractor subjectively assessed the quality performances of the subcontractor candidates. The duration, bid price and quality data obtained for all subcontractor candidates of 20 work packages are given in Table 3.

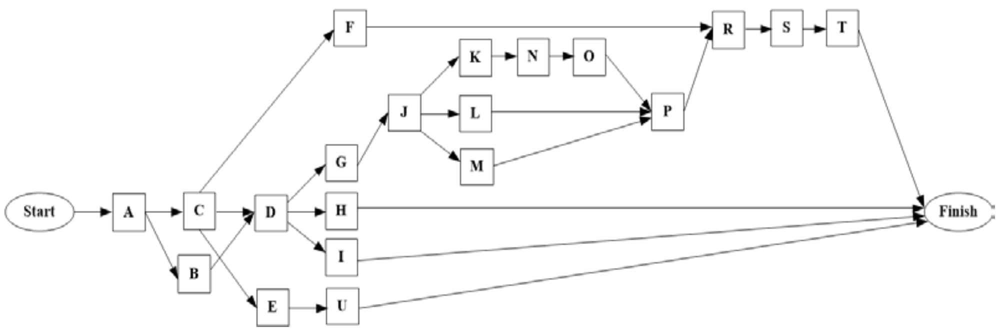

Fig. 3. Work packages network diagram.

20 work packages, which are included in the studied project, are as follows; *A*: Excavation works, *B*: Insulation works, *C*: Core construction works, *D*: Brick laying, *E*: Facade works, *F*: Elevator assembly, *G*: Plaster works, *H*: Mechanical works, *I*: Electrical works, *J*: Screed works, *K*: Plasterboard works, *L*: Epoxy coating, *M*: Marble coating works, *N*: Indoor insulation works, *O*: Ceramic tiles works; P: Door assembling, *R*: Painting works, *S*: Furniture and sanitary work, *T*: Carpet works, and *U*: Landscaping.

Table 2. Time, Cost, Quality Performances of Subcontractor Options According to the Work packages.

Work Packages	Subcontractor Option_1			Subcontractor Option_2			Subcontractor Option_3		
	Duration (days)	Bid Price (TL)	Quality (%)	Duration (days)	Bid Price (TL)	Quality (%)	Duration (days)	Bid Price (TL)	Quality (%)
A	90	2,700,800.00	74	95	2,680,700.00	70	100	2,590,000.00	68%
B	60	369,700.00	79	68	362,500.00	77	72	354,800.00	75%
C	120	3,269,500.00	71	130	3,190,800.00	69	140	3,050,900.00	65%
D	30	185,400.00	87	33	180,200.00	86	35	173,600.00	83%
E	120	912,200.00	90	125	889,900.00	85	130	877,400.00	80%
F	90	554,400.00	85	95	550,800.00	83	100	549,600.00	80%
G	30	236,400.00	72	33	233,700.00	70	36	231,900.00	69%
H	120	1,268,500.00	77	130	1,270,200.00	85	135	1,310,000.00	95%
I	120	1,039,500.00	82	125	1,090,100.00	89	130	1,100,700.00	93%
J	20	267,200.00	70	27	262,900.00	75	32	259,600.00	78%
K	50	395,500.00	88	55	390,400.00	92	60	388,200.00	94%
L	20	175,700.00	74	18	172,200.00	68	15	168,400.00	65%
M	15	123,000.00	77	14	120,800.00	72	13	118,600.00	69%
N	15	88,800.00	86	13	92,200.00	91	12	95,000.00	94%
O	20	148,300.00	88	18	152,600.00	91	16	155,000.00	95%
P	15	142,900.00	79	16	137,700.00	75	19	136,300.00	68%
R	45	225,500.00	81	42	230,000.00	77	35	232,100.00	73%
S	20	281,200.00	95	25	278,600.00	90	30	265,800.00	87%
T	20	1,386,300.00	87	26	1,340,100.00	82	32	1,288,400.00	79%
U	60	175,500.00	91	55	180,200.00	85	50	182,000.00	82%

3. Implementation of the developed multi objective optimization model in the case study

In the studied project, the general contractor's main objective is to work with the most appropriate combination of subcontractors, which offers the minimum project duration and cost and maximum quality. Equation (1) represents the fitness function of the problem.

$$f \rightarrow Minimization\ (f_T, f_C, \frac{1}{f_Q}) \tag{1}$$

In the first phase of the optimization algorithm, the total duration of the project was determined. In order to calculate the total duration of the trade center project, the critical path method (CPM) was used. In this method, the longest path from the starting node (i.e., *Start*) to the ending node (i.e., *Finish*) in the network is equal to the project duration. According to the network diagram presented in Figure 1, there are 14 alternative paths (see Table 3). The lengths (i.e., durations) of all paths were calculated by taking the sum of the durations of the work packages in these paths and the longest one is considered as the total project duration. Since the combination of subcontractors changes in each run of the model, the critical path also changes. Therefore, the total project duration was re-calculated in each run.

Table 3. Potential paths in the studied trade center project.

Paths	Work packages included in the path	Paths	Work packages included in the path
Path #1	A-C-D-H	Path #8	A-B-D-H
Path #2	A-C-D-I	Path #9	A-B-D-I
Path #3	A-C-D-E-U	Path #10	A-B-D-E-U
Path #4	A-C-F-R-S-T	Path #11	A-B-F-R-S-T
Path #5	A-C-D-G-J-M-P-R-S-T	Path #12	A-B-D-G-J-M-P-R-S-T
Path #6	A-C-D-G-J-L-P-R-S-T	Path #13	A-B-D-G-J-L-P-R-S-T
Path #7	A-C-D-G-J-K-N-O-P-R-S-T	Path #14	A-B-D-G-J-K-N-O-P-R-S-T

After determining the total duration of the project using the CPM, the total cost of the project was calculated. Since the owner applied penalty in the case of delay and incentive payment in the case of early finish in the studied trade center project, the total cost of the project dependent on the total project duration (*T*) and the due date of the project (*D*) . The total cost of the project was calculated using Equation (2).

$$C = \begin{Bmatrix} \left(\sum_{i=1}^{m} \sum_{j=1}^{n_i} C_{ij} + IC \times T + \beta [T - D] \right); & if\ T > D \\ \left(\sum_{i=1}^{m} \sum_{j=1}^{n_i} C_{ij} + IC \times T - I[D - T] \right); & if\ T < D \\ \left(\sum_{i=1}^{m} \sum_{j=1}^{n_i} C_{ij} + IC \times T \right); & if\ T = D \end{Bmatrix} \quad (2)$$

where C is the total cost of the project, C_{ij} is the bid price offered by the subcontractor option j for the work package i, m is the number of total work packages, n_i is the number of subcontractor options for the work package i, IC is the daily indirect cost, β is the daily penalty cost, T is the total duration of the project, D is due date of the project, and I is the daily incentive cost. The due date of the trade center project (D) was *500* days and the daily indirect cost was *500* TL. If the project finishes earlier than the due date (i.e., $T <$ D), the general contractor would receive incentive payment, which is *750* TL/day. In addition to that, the general contractor would pay penalty cost if the project finishes later than the due date schedule (i.e., $T > D$). The penalty cost was *1,000* TL/day. The overall quality of the trade center project was determined using Equation (3).

$$Q = \sum_{i=1}^{m} w_i \times q_i \quad (3)$$

where Q is the overall quality of the project, w_i is the weight of work package i on the overall quality of the project, q_j is the quality performance of the selected subcontractor for work package i. In this project, the weight of each work package was considered to be equal.

4. Findings and Discussion

Previous studies on “Time-Cost-Quality trade-off problem in construction projects” [19, 27, 28] were investigated in order to select the most suitable control parameters for the generated algorithm. According to these studies, the control parameters of NSGA-II were set in the following ranges; population size: *200-300*, the crossover rate: *0.5-0.85*, and the mutation rate ranges: *0.02-0.55*. The parameters of the NSGA-II algorithm were set as follows: population size: *200*, mutation rate: *0.02* and crossover rate: *0.85*. In this study, the SolveXL software program was used. Six different solutions, which represent Pareto optimal front are presented in Table 4.

Table 4. Pareto optimal subcontractor combinations.

Solution	Optimal subcontractor combinations*	Project performance		
		Time (day)	Cost (TL)	Quality (%)
1	1-3-1-1-3-2-1-2-1-1-1-1-1-3-3-1-1-1-1-1	**468**[a]	**14,117,600.00**[a]	**82**[a]
2	3-1-3-1-2-1-1-2-1-1-3-3-1-3-3-1-3-1-2-1	504	13,811,000.00	81.2
3	1-3-1-1-2-3-1-3-2-1-1-2-2-3-3-1-3-1-1-2	**458**[b]	14,212,400.00	81.7
4	3-3-3-3-3-3-1-1-1-1-1-3-3-1-1-2-3-3-3-1	523	**13,711,500.00**[c]	77.7
5	1-1-1-1-1-1-1-3-3-3-3-1-1-3-3-1-1-1-1-1	490	14,284,500.00	**84.6**[d]
6	3-3-3-1-2-1-1-2-1-1-1-1-1-3-3-1-3-1-1-1	488	13,835,900.00	81.4

* Each solution is represented by a sequence that indicates the selected subcontractor option for each work package.
[a] Best compromise; [b] Minimum Time; [c] Minimum Cost; [d] Maximum Quality.

If the priority was given to the minimization of total project duration (i.e., *Time: 458 days*), then the subcontractor combination indicated in the third solution should be selected by the general contractor. If the priority was given to the minimization of the total cost of the project (i.e., *Cost: 13,711,500.00 TL*), then the subcontractor combination indicated in the fourth solution should be selected. If the priority was given to the maximization of the quality of the project (i.e., *Quality: 84.6%*), then the subcontractor combination indicated in the fifth solution should be selected. On the other hand, if the general contractor gives equal priority to time-cost-quality (i.e., *Time: 468 days*, *Cost: 14,117,600.00 TL, and Quality: 82%*), then the subcontractor combination indicated in the first solution should be selected. While considering the estimated cost (i.e., *15,869,770.00 TL*) and the anticipated duration (i.e., *500 days*) for the trade center project, the best compromise solution (i.e., *Time: 468 days*, *Cost: 14,117,600.00 TL, and Quality: 82%*) obtained from NSGA-II algorithm is quite satisfactory. Figure 4 presents the best compromise solution of the proposed algorithm including whole work packages and project performance values. It can be concluded that the subcontractor combination (i.e., *subcontracting plan for the project A:1 , B:3, C:1, D:1; E:3; F:2; G:1; H:2; I:1; J:1; K:1; L:1; M:1; N:3; O:3; P:1; R:1; S:1; T:1; U*:1) indicated in the first solution is the best compromise solution, which satisfies all objectives simultaneously. In the studied project, the company management preferred to work with the subcontractors identified in the first solution and did not experience any serious problems.

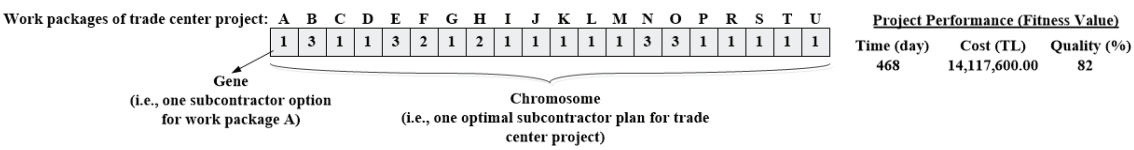

Fig. 4. Representation of one optimal subcontractor combination in the NSGA-II algorithm.

5. Conclusion

In this study, selection of subcontractors for the all work packages in a construction project was made considering time, cost and quality performances. A real-life trade center project was selected as a case study and the actual data regarding alternative subcontractors were collected. The most appropriate subcontractors, who would carry out work packages in the case study, were selected successfully using the genetic algorithm based multi objective optimization model. The proposed model enabled the general contractor to select the optimal subcontractor combination for all work packages by considering the interactions between the subcontractors and their impacts on the overall project performance in terms of time, cost and quality. In the literature, the studies on the subcontractor practices mainly focus on two aspects, which are identifying the criteria considered in the subcontractor selection process and developing tools or methods for selecting the subcontractor, which will be in charge of one work package (e.g., insulation works), among different alternative subcontractors considering several criteria. The main contribution of this study is to propose a multi-objective optimization model, which uses the main objectives (i.e., *Time, Cost, and Quality*) of contract requirements to select the most appropriate subcontractors for each work package that constitute the entire project simultaneously. The interaction between the subcontractors of the entire project is also taken in consideration in this model. Therefore, the main contractors select the subcontractors based on the contract requirement or their targets for the project in question.

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