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Optimizing Three-Dimensional Trade-Off Problem of Time–Cost–Quality over Multi-Mode Projects with Generalized Logic

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Abstract: Clients typically tend to aim for reasonable prices, minimum possible makespans, and the best quality for the construction projects that they engage in. Evidently, weighing the available offers and coming up with an optimal decision can pose challenges for the decision makers. In this regard, the generation of a tool that helps decision makers strike a proper balance among the conflicting project objectives (i.e., time, cost, and quality) is imperative. To this end, this study proposes a method which assists in the selection of the best compromise choices among the options available for each of the project activities. In addition to the time and cost, the proposed method is designed to bring the quality aspect into the equation as well. To quantify the quality, a value referring to the weighted importance and performance of each activity is used. The proposed method is based on a modified multi-objective genetic algorithm (GA) that incorporates the domination concept for the selection of the best solutions out of the potential candidates. The GA-based method is capable of handling an unlimited number of precedence relationships for each activity, and above all, it is able to capture and unravel any type of logical relationship. This very feature significantly improves the practical relevance of this research, as the parallelization of activities is a common practice in real-life projects. Planners benefit from the various types of relationships (i.e., Start to Start, Start to Finish, Finish to Start, and Finish to Finish), and the concept of lag time frequently introduces parallelization into the network. Overlapped activities, in turn, help reduce the unwanted idle times and speed up the project significantly. Accordingly, in order to demonstrate the application and effectiveness of the proposed model, it has been used in the solution of four time–cost–quality (TCQ) trade-off problems, three of which are generated within the context of this paper. The practiced instances include a small benchmark TCQT problem with 18 activities taken from the literature in addition to more complex 29- and 63-activity TCQTPs produced herein based on benchmark time–cost trade-off problems. The performance of the presented approach is ultimately examined over a large-scale, real-case construction project with over four hundred activities and generalized logic in an unprecedented attempt to validate a model in the realm of TCQTPs. The successful results of the experiments reveal the effectiveness of the proposed model and corroborate the feasibility of its application by the planners amidst arduous decision-making processes.

Keywords: time–cost–quality trade-off problem; genetic algorithm; optimization; generalized precedence relationships

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1. Introduction

Preparing a project schedule that satisfies both the completion deadline and the predefined budget is a challenge in itself. A project's success is often particularly assessed based on its duration and cost [1]. In the construction management domain, numerous methods have been proposed by scholars for the simultaneous optimization of the project duration and cost. This optimization problem is known as the time–cost trade-off problem (TCTP) and mainly aims to enable the selection of the best combination of construction techniques. This is because the employed construction technique is a key determinant of the productivity, and thus, the time and cost associated with a task's performance. Typically, high-priced construction techniques tend to be more productive and are quicker, although, a shorter duration may raise problems with the quality of the project. This, in turn, may result in higher maintenance and repair costs, leave the stakeholders dissatisfied, and may ultimately lead to claims and disputes [2]. Furthermore, additional costs would be required to meet the acceptable level of quality. Accordingly, Baccarini [3] refines the previous definition of project success as meeting the quality output standards while achieving the time and budget objectives [4]. Therefore, the maximization of quality should also be targeted while minimizing the time and cost of the project. Deciding among the bids/alternatives that offer diverse combinations of time, cost, and quality is an arduous and complicated task, especially if such decisions are to be made for the entire project. The optimal selection of such execution modes is referred to as the time–cost–quality trade-off problem (TCQTP). Solving this problem, although computationally intractable in many cases, can significantly contribute to the proper planning and control of construction projects.

Respecting the significance of quality, there has been an increased attention to project quality by governments. This has led to several advancements and studies focusing on and proposing optimization methods to enhance project quality. In a primitive study by Babu and Suresh [5], a linear programming model was presented for unravelling the trade-offs among the objectives time, cost, and quality by assuming a linear relationship among the three objectives. Later, Khang and Myint [6] validated Babu and Suresh's [5] model by applying it as a solution for a cement factory construction project. Pollack-Johnson and Liberatore [7] proposed two mixed-integer linear programming models by formulating the duration and cost as constraints for the quality maximization problem. Tareghian and Taheri [8] proposed the electromagnetic scattering search method for the discrete version of this problem. El-Rayes and Kandil [9] used a genetic algorithm to locate optimal Pareto fronts. They used a highway construction project to examine the trade-offs among the three main project objectives. Achieving optimal Pareto fronts was also attempted by Afshar et al. [10], for which a multi-colony ant algorithm was employed. Zhang and Xing [11], highlighting the difficulty of assigning deterministic values for the time, cost, and especially quality, practiced particle swarm optimization for the fuzzy time–cost–quality trade-off problem. In another fuzzy-based approach, Mungle et al. [12] used the same highway construction project described by El-Rayes and Kandil [9] to test the practicality of their genetic algorithm. Zhang et al. [13] implemented program evaluation and review techniques instead of the classical critical path method in their immune genetic particle swarm optimization algorithm. Tran et al. [14] studied a hybridized algorithm for the TCQTP, which was developed by integrating the crossover operations of differential evolution into an artificial bee colony. Kazaz et al. [15] proposed a completely different approach, as their two-step methodology reduced the TCQTP to a bi-objective time–cost trade-off problem through analyzing the quality separately. Wood [16] studied a fuzzy memetic algorithm for the stochastic TCQTP, in which the degree of uncertainty for the trio of objectives was high. More recently, an opposition-based multiple-objective differential evolution algorithm was used by Luong et al. [17] to deal with TCQTPs. An improved particle swarm optimization algorithm was practiced by Song and Hou [18] for the continuous TCQTP, with two modes, i.e., normal and compressive, for activities. A non-dominated sorting genetic algorithm was employed by Wang et al. [19], which took into account the impact of working hours per day as well as the number of working days per shift while analyzing TCQTPs. Another fuzzy multi-criteria decision-making method was exploited by Banihashemi et al. [20], in which the SWARA (Stepwise Weight Assessment Ratio Analysis) method in addition to TOPSIS (Technique for the Order Preference by Similarity to Ideal Solution) was used to determine weights and to rank activity modes.

In a more recent study, Nguyen et al. [21] presented a free-parameter whale optimization algorithm for tackling TCQTPs over repetitive projects and used a sewer system project to demonstrate the efficiency of their method.

Despite the large number of innovative TCQTP algorithms, to the best of the authors' knowledge, Khalili-Damghani et al.'s [22] study stands out as the only attempt that has focused on TCQTPs with generalized precedence relationships. Epsilon-constraint, efficient epsilon-constraint, particle swarm optimization, and multi-start, partial-bound enumeration algorithms have been employed by Khalili-Damghani et al. [22] to solve complex TCQTPs. Nevertheless, none of the existing studies have thoroughly investigated real-life-sized construction projects, particularly those involving generalized logic. More specifically, in Khalili-Damghani et al.'s [22] study, no benchmark construction projects were used, and the 4 methods were compared based on randomly generated instances with 10, 50, and 100 activities. On the other hand, even the more recent studies employ problems with 12 [18], 18 [17,20], 20 [19], 32 [20], 33 [21], and 60 [14] activities, all assuming the Finish-to-Start precedence relationship with no lag time. Pertaining to this matter, Orm and Jeunet [23] also highlight the limitations of the extant literature, wherein only six projects ranging from two to fifty-two activities have been practiced so far.

Moreover, genetic algorithm-based optimization techniques have demonstrated reasonable effectiveness in solving a variety of problems, such as resource-leveling problems [24], tower crane layout optimization [25], and façade pattern optimization [26]. This has motivated the authors to develop a genetic algorithm-based method capable of addressing computationally complex time–cost–quality trade-off problems that incorporate networks with generalized logic. Accordingly, new TCQTP test examples have been introduced by modifying two widely practiced benchmark time–cost trade-off problems. In addition, an actual large-scale TCTP from the literature, with more than four hundred activities, has been extended to include quality performance for each execution mode provided for the project activities. The new test instances, along with an existing problem, have been employed to experiment with the capabilities of the proposed algorithm. This research, therefore, makes three main contributions to the extant literature: First, the paper proposes a capable multi-objective genetic algorithm to facilitate the TCQ trade-off. Second, this research develops large-scale instances to enable extensive TCQT analyses in construction projects. Third, assisting in the selection of the near-optimum trade-off values among the three chief project objectives is regarded as one of the study's most important managerial and practical implications.

The remainder of this paper is structured as follows: Section 2 describes the problem. In Section 3, the methodology is outlined. Section 4 presents the test examples and the associated results. Finally, concluding remarks on the present work are given in Section 5.

2. Problem Description

The overall duration of a project can be determined using the activity times through the critical path method. The overall direct cost, on the other hand, can be calculated by aggregating the direct costs of individual project activities. The quantification of the quality, however, may entail inherent complexities. Numerous studies have focused on investigating and examining the quality of construction projects. Quality has been linked to client satisfaction; more owner satisfaction is a sign of better project quality, and vice versa. According to Heravi and Faeghi [27], the grayscale, which uses white (i.e., 0) to designate the worst quality and black (i.e., 256) to represent the best performance, can be used to indicate the level of quality satisfaction. Mungle et al. [12] take an alternative approach for the assessment of quality, as they break down the quality of each activity into many key indicators based on expert judgements. The quality of each activity is measured by assigning weights to the constituent quality indicators based on their relative importance to the other. Quality performance of the project is then measured by the aggregation of these indicators. For instance, compressive strength, flexural strength, and ride quality are regarded as the constituent quality indicators of concrete paving [11,28,29].

Hence, such quality indicators might be specified in the agreement to document how the project, its activities, and their deliverables will demonstrate compliance with the performance and quality requirements of the project.

Song and Hou [18] suggest the utilization of matrix data analysis and the vector plot method for the evaluation of engineering quality objectives. Orm and Jeunet [23] point out that quality has never been directly expressed as a function of resources but rather that quality depends on the cost, which itself is contingent upon resources. Nevertheless, projects may suffer from quality issues when accelerated due to overstaffing and overtime. This study proposes the classification of quality quantification techniques into three categories as follows: (i) models integrating quality implicitly with the cost and/or duration of rework; (ii) models that formulate the quality of an activity as a continuous function of its duration and/or cost; and (iii) models that assume the quality is an estimated parameter in each execution mode and is expressed as a weighted sum of quality indicator values. On the basis of previous studies, e.g., [9,12], the current study employs the third category mentioned in [23] and describes the quality level of every activity using a percentage between 0 and 100. As per this weighted approach, weights can be assigned to project activities based on their contribution to the overall quality, which is often directly proportional to each activity's corresponding portion of the contract price. Finally, the total cost of the project can be achieved through the summation of the overall indirect and direct costs. Moreover, it is the resource utilization plan and the execution methodology chosen for each activity that determines its duration, cost, and quality. That is, the time–cost–quality problem is, in essence, determining the optimal combination of resource utilization plans and the execution methodologies for every work item to locate the best compromise solution based on the project time, cost, and quality.

Problem Formulation

Determining the optimal combination of construction methods is aimed to arrive at an optimal compromise among the project objectives of time, cost, and quality. The optimization of these objectives entails the development of unique formulations. To this end, the formulation of De et al. [30] can be modified to include the indirect cost and delay penalty for the minimization of the sum of direct and indirect costs of a project as given in Equation (1).

$$\text{minimize} \sum_{j=1}^{S}\sum_{k=1}^{m(j)}(dc_{jk}x_{jk}) + D\times ic + Delay\times dp \tag{1}$$

$$\sum_{k=1}^{m(j)} x_{jk} = 1, \quad \forall j = \{1,\ldots,S\} \tag{2}$$

$$\sum_{k=1}^{m(j)} d_{jk}x_{jk} + St_j \le St_l, \quad \forall l \in Sc_j \quad \text{and} \quad \forall j = \{1,\ldots,S\} \tag{3}$$

$$D \ge St_{S+1} \tag{4}$$

$$Delay \ge D - \text{Deadline} \tag{5}$$

$$St_0 = 0 \tag{6}$$

$$x_{jk} \in \{0,1\}, \quad \forall j = \{1,\ldots,S\} \quad \text{and} \quad \forall k = \{1,\ldots,m(j)\} \tag{7}$$

$$St_j \ge 0, \quad \forall j = \{1,\ldots,S\} \tag{8}$$

$$D, Delay \geq 0 \tag{9}$$

Here, S = the number of activities; 0 and $S+1$ denote the start and finish milestones, respectively; dc_{jk} = direct cost of the k-th mode of the j-th activity; x_{jk} = mode selection binary variable; D = total duration; ic = rate of daily indirect cost; $Delay$ = number of days delayed; dp = rate of delay penalty; d_{jk} = duration of the k-th mode of the j-th activity; $m(j)$ = number of modes for the j-th activity; Deadline = project deadline; St_j = start time of the j-th activity; and Sc_j = activity j's set of immediate successors.

For the maximization of the project's overall quality, the formulation given in Equation (10) is required to be optimized while satisfying the conditions mentioned in Equations (3)–(9).

$$\text{maximize} \sum_{j=1}^{S} w_j \sum_{k=1}^{m(j)} q_{jk} x_{jk} \tag{10}$$

$$\sum_{k=1}^{m(j)} x_{jk} = 1, \quad \forall j = \{1, \ldots, S\} \tag{11}$$

Here, w_j = weight of the j-th activity relative to other project activities ($\sum_{j=1}^{S} w_j = 1$); and q_{jk} = quality performance of the j-th activity when the k-th mode is selected.

3. Methodology

Normally, in a TCQTP, the project objectives of time, cost, and quality have to be optimized simultaneously to arrive at an optimal compromise among these objectives. In a more challenging version of a TCQTP, the determination of the Pareto front—comprising the nondominated time–cost–quality profile over the feasible project duration realizations—is targeted. For the Pareto front TCQTP, being the main focus of this study, a customized genetic algorithm (GA) has been developed that incorporates the major objective functions given in the previous equations. The idea of solving TCQTPs using a GA-based method has been successfully applied in the literature to deal with challenging construction management problems. Yet, large TCQTPs, including construction projects with generalized precedence relationships, have not been properly addressed in the previous studies. To the best of the authors' knowledge, this manuscript is the first study that proposes a method capable of capturing and unraveling TCQTPs in large-scale construction projects with any type of logical relationship.

The developed method measures the total project duration using the classical critical path method (CPM) by considering the type of relationship as well as the amount of lag/lead time between the activities and their corresponding predecessor(s)/successor(s). As shown in Figure 1, the various forms of relationships between the activities not only help secure the hard and/or soft dependencies but also facilitate the introduction of parallelism into the project network.

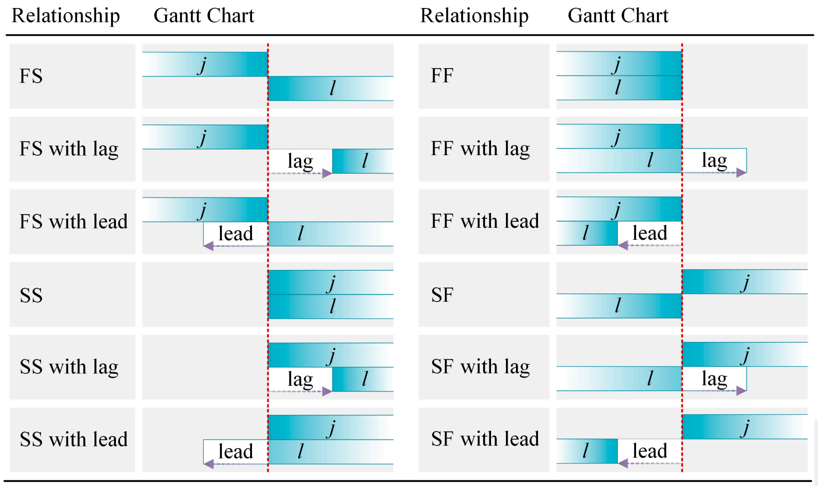

Figure 1. Various types of logical relationships and their representations.

The relationship between the activities can be defined in multiple forms, namely, Start to Start (SS), Start to Finish (SF), Finish to Start (FS), and Finish to Finish (FF). The various relation types can also be combined with either a lag time or a lead time for delaying or advancing the start/finish time of any immediate succeeding activity, respectively. These relationships can be formulated by modifying Equation (3) as follows:

For an FS relationship between the j-th and l-th activity:

$$\sum_{k=1}^{m(j)} d_{jk} x_{jk} + St_j + L_{jl} \le St_l \tag{12}$$

For an FF relationship between the j-th and l-th activity:

$$\sum_{k=1}^{m(j)} d_{jk} x_{jk} + St_j + L_{jl} \le \sum_{k=1}^{m(l)} d_{lk} x_{lk} + St_l \tag{13}$$

For an SS relationship between the j-th and l-th activity:

$$St_j + L_{jl} \le St_l \tag{14}$$

For an SF relationship between the j-th and l-th activity:

$$St_j + L_{jl} \le \sum_{k=1}^{m(l)} d_{lk} x_{lk} + St_l \tag{15}$$

where $m(l)$ = number of modes for the l-th activity; and L_{jl} = amount of lag/lead time between the j-th activity and l-th activity.

The overall project quality, on the other hand, is essentially portrayed by the quality of the individual project activities. Every activity's quality, on the other hand, is typically governed by several measurable indicators including the material, equipment, and labor [17]. Generally, such quality indicators are considered for the measurement and quantification of the quality performance of the activities. For each indicator, a relative weight proportional to its contribution to the activity quality is assigned. In a similar fashion, a relative weight, denoting the impact of each activity on the overall project quality, is determined by correlating an activity with the performance of the end product of the project [12]. In the proposed method, all the several activity-level quality indicators have been aggregated into a single value representing the quality performance of a particular execution mode. As a result, for any time–cost–quality mode of any activity, a single quality value that ranges from 0 to 100 percent is determined, reflecting the degree to which the quality requirements are satisfied. In the proposed model, it is assumed that such quality values are decided based on the results of particular experiments and/or expert judgments. Corresponding quality values of the selected modes along with the activity weights will then be used for the measurement of the overall project quality performance in percentages.

Multi-Objective Genetic Algorithm

Since Holland [31] first suggested the genetic algorithm (GA), it has been the focus of the well-established field of optimization research. The GA is an optimization technique inspired by the principles of natural selection and genetics. It is designed to initiate a population, within which each potential solution is represented as a chromosome. It uses genes to record data on each design/decision variable, and akin to more modern evolutionary algorithms, selection, crossover, and mutation are the primary operators of the GA, mimicking the process of reproduction and genetic variation. Through successive generations, the GA uses a fitness (objective) function to assess the fitness of every member of the population. The best solutions with higher fitness are selected and used for further reproduction. The process of reproduction is generally repeated until reaching a near-optimal or optimal solution. The original GA has been modified and extended in numerous ways for the purpose of solving many complex problems. The GA has paved the way for further advancements and has encouraged the development of several other nature-inspired algorithm.

The application of the GA ranges from single- to multi-objective optimization [32], and as mentioned earlier, several efficient variants of the algorithm have been suggested in the literature. Unlike intelligent methods such as the GA, the weighted approaches and constraint methods can convert multi-objective problems into single-objective problems, which complicates locating multiple solutions at once, rendering them unsuitable for engineering applications [14,18]. NSGA-II [33] is noticeably one of the more successfully practiced intelligent methods. Akin to NSGA-II, the GA practiced in this study starts by generating a random population of size N. At each iteration t, Equations (1) and (10) are used to obtain the three objective function values of time, cost, and quality performance based on the modes selected and the CPM calculations performed according to Equations (12)–(15). As shown in Figure 2, solutions are then ranked based on the Pareto dominance optimality. The lowest rank of zero is assigned to the non-dominated solutions of the current population. Ranking is continued by incrementing the rank by one and assigning the new value to the non-dominated solutions among the non-ranked individuals of the current population. Assigning a larger rank to the non-ranked, non-dominated solutions continues until all the N individuals are ranked. In so doing, non-dominated solutions are given greater chance to be selected in the reproduction cycles. In addition, rank zero non-dominated individuals that form the Pareto front are copied to an external archive (O) at each iteration. This archive is designed to hold only the Pareto individuals by identifying and discarding those being dominated by the new members of the front. The current parent population is used to generate N offspring by performing roulette wheel selection, crossover, and mutation operations of the classical genetic algorithm. In the roulette wheel selection, the ranks assigned are used to control the probability of selection rather than the fitness values of the individuals. In the process of parent selection, the ranks are used as the only criterion; in case of a tie rank, an individual will be chosen randomly. Following the reproduction stage of the algorithm, N lowest-ranked individuals out of $|P|$ solutions will be retained for the subsequent generations. The algorithm will evolve the population by repeating the same set of operations t times. Ultimately, the GA will terminate and return the final Pareto solutions recorded in archive O.

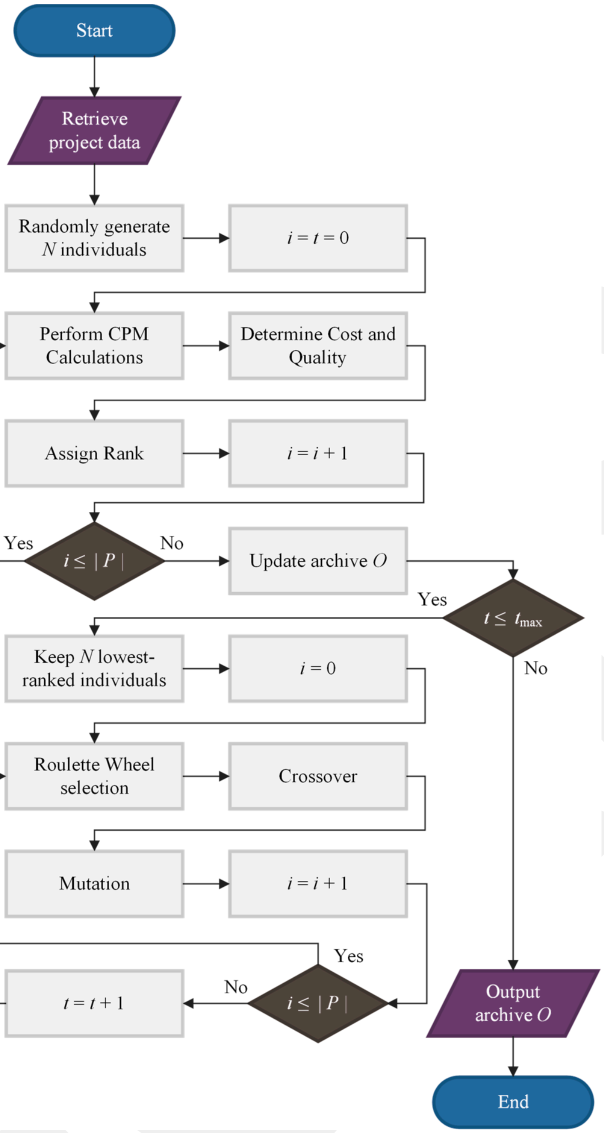

Figure 2. Flowchart of the practiced genetic algorithm.

4. Computational Experiments

Details of the practiced test instances, parameter configurations, as well as the obtained results are elaborated in this section. In order to demonstrate the application and effectiveness of the proposed method, in addition to an existing small-scale problem, two new time–cost–quality trade-off test examples have been introduced by modifying widely practiced time–cost trade-off problems drawn from the literature. The new test instances along with the existing problem have been employed to experiment the capabilities of the proposed algorithm. The proposed optimization algorithm is coded in C#, and all the experiments are conducted on a laptop computer.

4.1. Parameter Configuration

Trial runs were performed, and the parameters of the GA were configured to the values shown in Table 1, in line with the performance characteristics of the method. The population size (N) and generation number ($t_{\max}$) were set as multiples of the project size (S), and a crossover rate (P_{corss}) of 0.80 and a mutation rate (P_{mut}) of 0.01 were used for all the instances.

Table 1. Parameter configuration of multi-objective GA.

Parameter	Description	Value
N	Population size	50 *S*
$t_{\max}$	Generation	250 *S*
P_{cross}	Crossover rate	0.80
P_{mut}	Mutation rate	0.01

4.2. TCQT Test Examples

To exemplify the use and demonstrate the model's effectiveness, it was applied to four test instances with 18, 29, 63, and 447 activities. Of the examples practiced, the 18-activity problem is obtained from the literature, and the larger instances are developed based on two well-known time–cost trade-off problems in addition to an actual construction project. It is worth mentioning that several quality indicators and the aggregation process are not focused herein; instead, a single value ranging from 0 to 100 percent that represents the quality performance of a particular execution mode has been considered for the activities. Details of the instances are given below.

4.2.1. The 18-Activity Problem

El-Rayes and Kandil [9], by modifying the widely practiced 18-activity time–cost trade-off problem of Feng et al. [34], have introduced a TCQT problem whose activity table is shown in Table 2. This instance has been revised to accommodate the quality performance for each execution mode offered for the activities.

Table 2. Activity table for 18-activity TCQTP.

Act.	Precedence Relations	Activity Weight (%)	Duration (Day)	Cost (USD)	Quality (%)	Act.	Precedence Relations	Activity Weight (%)	Duration (Day)	Cost (USD)	Quality (%)
1	-	3	24	1200	62.50	10	2FS, 6FS	1	33	320	65.40
			21	1500	73.70				22	400	80.60
			16	1900	82.90				15	450	95.20
			15	2150	89.50	11	7FS, 8FS	2	20	300	62.50
			14	2400	98.40				16	350	72.90
2	-	5	25	1000	62.20				12	450	95.70
			23	1500	73.60	12	5FS, 9FS, 10FS	3	30	1000	61.80
			20	1800	86.20				28	1500	71.70
			18	2400	91.40				24	1750	87.30
			15	3000	96.60				22	2000	98.05
3	-	8	33	3200	61.85	13	3FS	7	24	1800	61.40
			22	4000	80.45				18	3200	72.80
			15	4500	99.25				14	4000	97.40
4	-	11	20	30,000	61.15	14	4FS, 10FS	6	18	2200	63.70
			16	35,000	73.25				15	2400	79.50
			12	45,000	96.85				9	3000	99.30
5	1FS	10	30	10,000	61.60	15	12FS	7	16	3500	99.40
			28	15,000	74.80	16	13FS, 14FS	3	30	1000	62.90
			24	17,500	91.40				28	1500	73.10
			22	20,000	99.20				24	1750	79.20
6	1FS	11	24	18,000	62.00				22	2000	87.00
			18	32,000	76.25				20	3000	97.10
			14	40,000	96.25	17	11FS, 14FS, 15FS	6	24	1800	62.50
7	5FS	10	18	22,000	63.70				18	3200	73.30
			15	24,000	71.30				14	4000	97.90
			9	30,000	96.00	18	16FS, 17FS	5	18	2200	65.35
8	6FS	1	24	120	61.00				15	2400	74.90
			21	208	68.00				9	3000	97.45

			16	200	75.00
			15	215	83.00
			14	220	95.00
9	6FS	1	25	100	63.50
			23	150	73.00
			20	180	84.50
			18	240	94.50
			15	300	99.50

The results of the GA for the small-scale TCQT problem are summarized in Table 3. The customized GA with the parameter settings mentioned in Table 1 was able to locate 413 Pareto optimal solutions in 83 s. The solutions achieved ranges from 104 to 159 for the duration, USD 100,870 to USD 167,048 for the cost, and 66.31% to 96.20% for the quality performance. For the sake of brevity, only a select number of Pareto solutions are shown in Table 3. All Pareto front solutions can be found in Abdulsattar's [35] study and are presented graphically in Figure 3. This 3D illustration clearly demonstrates the relationship among project duration, cost, and quality and may aid decision makers in evaluating various potential project performance plans.

Table 3. Selected Pareto solutions for 18-activity TCQTP.

Sol. No.	Dur. (Day)	Cost (USD)	Quality (%)	Mode Selection
1	104	164,820	93.06	5 5 1 3 3 3 3 1 5 3 2 4 3 3 1 5 3 3
147	115	152,880	92.41	3 5 3 1 4 3 3 3 3 2 3 3 3 3 1 5 3 3
315	128	141,395	91.12	2 4 3 3 3 1 3 4 3 2 3 4 3 3 1 3 3 3
364	134	126,740	87.25	3 4 3 1 3 1 3 1 5 1 3 4 3 3 1 3 3 3
406	149	105,515	74.96	4 1 3 1 1 1 1 4 1 2 3 1 3 3 1 1 1 2
413	159	102,150	70.43	1 1 3 1 1 1 1 3 2 3 3 1 1 2 1 2 1 1

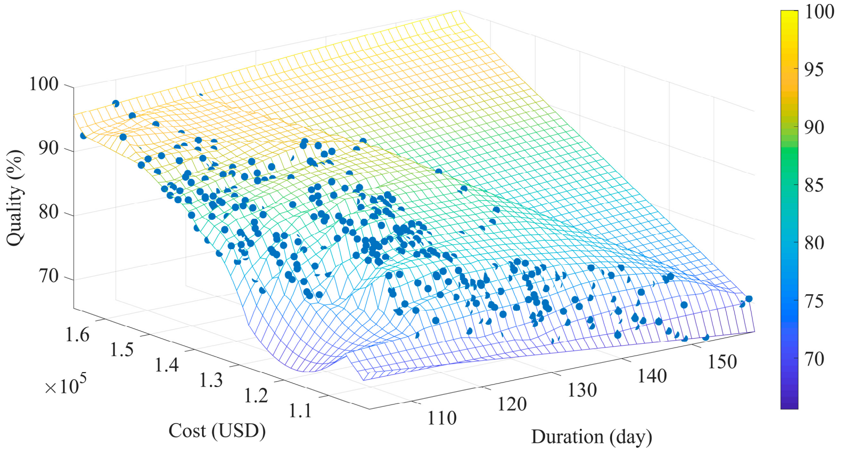

Figure 3. Pareto front for 18-activity TCQTP.

The GA's performance along with the performances of the previous methods included in the literature are tabulated in Table 4. In this table, the sample Pareto optimal solutions reported by El-Rayes and Kandil [9], Mungle et al. [12], and Luong et al. [17] form the basis for the comparisons. In El-Rayes and Kandil's [9] study, non-dominated solutions for five different durations have been reported. Mungle et al. [12] present solutions matching three of the durations described by El-Rayes and Kandil [9], while Luong et al. [17] provide five results matching the durations given either in the foregoing studies and/or the present study. Among the results obtained using the present GA, the solutions corresponding to all seven durations have been located. For a duration of 104 days, both El-Rayes and Kandil [9] and the present study are shown to obtain better results than Mungle et al. [12], since the solution provided in the latter study is more expensive and is lower in quality. Though, the result achieved by Luong et al. [17] for 104 days dominates all the solutions found using the rest of the models, with a lower cost and higher quality performance. For the same duration of 104 days, the results of El-Rayes and Kandil [9] and the present study are incomparable, since none of the solutions dominate the other. For the duration of 109 days, the results provided in the four studies are equally good, with El-Rayes and Kandil [9] reporting an execution plan with the cheapest/lowest quality and Luong et al. [17] determining the costliest/highest quality performance. For the duration of 114 days, the result provided by El-Rayes and Kandil [9] is dominated by Luong et al.'s [17] result, while the other three studies are equally good, with Luong et al. [17] reporting the cheapest execution plan and this study finding the costliest/highest quality performance. For the durations of 115 and 124 days, El-Rayes and Kandil [9] and the present study achieve incomparable results; that is, neither of the solutions corresponding to the same duration provide an execution plan that is simultaneously cheaper and of higher quality. Finally, for the durations of 120 and 159 days, Luong et al. [17] and the current study achieve incomparable and equally good results. Furthermore, an average CPU time of 1092 s is required by the method proposed by Mungle et al. [12] for the solution of the 18-activity problem, while taking a shorter period of 83 s for the present method to unravel the same TCQT problem. El-Rayes and Kandil's [9] method, on the other hand, was able to achieve 305 non-dominated solutions along the Pareto front, which is significantly less than the 413 Pareto solutions of the present study.

Table 4. Comparison of results for 18-activity TCQTP.

Dur. (Day)	El-Rayes and Kandil [9]		Mungle et al. [12]		Luong et al. [17]		This Study	
	Cost (USD)	Quality (%)	Cost (USD)	Quality (%)	Cost (USD)	Quality (%)	Cost (USD)	Quality (%)
104	166,320	95.00	168,480	85.66	164,715	96.17	164,820	93.06
109	121,350	77.00	136,975	77.10	167,695	97.06	145,470	89.78
114	105,470	71.00	131,568	77.43	105,270	71.55	151,400	91.90
115	141,620	90.00	-	-	-	-	152,880	92.41
120	-	-	-	-	105,570	72.69	106,160	75.97
124	104,620	72.00	-	-	-	-	143,690	92.09
159	-	-	-	-	99,870	65.24	102,150	70.49

4.2.2. The 29-Activity Problem

This problem was originally introduced by Chassiakos and Sakellaropoulos [36] as a highway upgrading project. Later, Sonmez and Bettemir [37] slightly modified this problem by relaxing the external constraints that limited the activity execution times. This project was employed to demonstrate the trade-off between the time and cost, and thus, did not include any quality data. Therefore, in the present work, Sonmez and Bettemir's [37] version has been further modified to also accommodate quality performance for each execution mode provided for the project activities. Table 5 presents the activity table for this TCQT problem. This project is assumed to have an indirect cost rate of EUR 1200/day, a delay penalty of EUR 1500/day, an incentive payment of EUR 500/day, and a desired completion duration of 240 days.

Table 5. Activity table for 29-activity TCQTP.

Act.	Precedence Relations	Activity Weight (%)	Duration (Day)	Cost (USD)	Quality (%)	Act.	Precedence Relations	Activity Weight (%)	Duration (Day)	Cost (USD)	Quality (%)
1	-	2	15	60,000	63.10	17	15FS−10, 15FF	2	25	23,000	62.10
			12	68,000	94.10				20	26,000	81.10
2	1SS+5, 1FF	4	25	30,000	65.70				12	35,000	94.50
			20	38,000	84.70	18	15FS	2	20	14,000	67.10
			15	44,000	93.10				15	18,000	86.10
3	1SS+10, 1FF+3, 2SS+10, 2FF+3	2	25	50,000	65.60				12	24,000	95.70
			20	54,000	84.60	19	15FS+12	4	25	14,000	62.40
			15	60,000	95.70				20	19,000	81.40
4	3FS	7	12	17,000	61.50				15	24,000	97.10
			9	21,000	94.50	20	17SS+10, 17FF+5	3	20	38,000	62.20
5	4FS	1	6	3000	97.60				15	42,000	93.20
6	1FS	2	12	27,000	62.50	21	16FS−10, 16FF, 20SS+12, 20FF+2	3	40	42,000	61.90
			9	32,000	93.50				35	50,000	80.90
7	6SS, 6FF	7	6	8000	99.60				30	58,000	92.20
8	7FS	5	20	44,000	67.50	22	21SS+15, 21FF+2	1	40	36,000	63.90
			15	48,000	86.50				30	48,000	82.90
			12	54,000	98.60				25	56,000	91.90
9	4FS, 8FS	6	12	15,000	62.20	23	22FS−15, 22FF	3	40	65,000	65.40
			9	22,000	93.20				35	74,000	84.40
10	5FS, 9FS	5	6	3000	99.30				25	79,000	93.90
11	5FS, 10FS	3	1	500	99.00	24	23SS+15, 23FF+5	2	9	7000	96.80
12	11FS	4	25	95,000	67.30	25	23FS−10, 23FF	4	25	45,000	62.50
			20	105,000	86.30				20	51,000	81.50
			15	109,000	95.00				15	59,000	96.50
13	12SS+6	5	15	34,000	63.30	26	25FS−10, 25FF	2	25	50,000	66.30
			12	41,000	82.30				20	58,000	85.30
			9	51,000	97.30				15	64,000	93.50
14	12FF+8, 13FF+8	2	12	9000	67.20	27	26FS−10, 26FF	6	30	60,000	61.70
			9	13,000	98.20				25	72,000	80.70
15	12SS+6, 12FF, 14FS−6, 14FF+10	6	25	30,000	62.80				20	78,000	99.30
			15	38,000	81.80	28	27FS−10, 27FF	1	12	9000	63.70
			12	42,000	97.20				9	13,000	82.70
16	15SS+10, 15FF	3	40	78,000	62.50				7	18,000	91.70
			35	85,000	81.50	29	18FS, 19FS, 24FS, 28FS	3	1	500	96.00
			30	90,000	92.80						

The performance of the present method over the first of the more complex TCQT problems, i.e., 29-activity problem, is displayed in Table 6. A multi-objective GA with parameters configured according to Table 1 has been able to achieve 73 non-dominated solutions within a period of 312 s. Pareto optimal solutions determined ranges from 174 to 219 for the duration, EUR 1,233,400 to EUR 1,340,400 for the cost, and 78.05% to 94.03% for the quality performance. The entire set of Pareto front solutions can be found in Abdulsattar's [35] work and are not repeated here for the sake of brevity and clarity. A select number of solutions along the Pareto front are given in Table 6. The complete set of Pareto front solutions are demonstrated graphically in Figure 4. The trade-off among the three main objectives of duration, cost, and quality can be followed from this figure, which might come in handy during the evaluation of alternative project execution plans.

Table 6. Selected Pareto solutions for 29-activity TCQTP.

Sol. No.	Dur. (Day)	Cost (USD)	Quality (%)	Mode Selection
1	174	1,290,800	90.78	2 3 3 2 1 1 1 3 2 1 1 3 3 1 2 3 2 2 1 1 2 3 3 1 3 3 3 3 1
29	183	1,270,100	89.56	1 2 3 2 1 1 1 3 2 1 1 2 2 1 2 3 2 2 2 2 1 3 3 1 3 3 3 1 1
57	192	1,340,400	94.02	2 3 2 2 1 2 1 3 2 1 1 3 3 1 3 3 3 2 2 2 3 3 2 1 3 3 3 2 1
68	202	1,242,400	83.87	1 1 1 2 1 1 1 1 2 1 1 2 1 1 2 3 2 1 1 2 1 2 3 1 2 3 3 1 1
73	219	1,234,300	78.30	1 1 1 2 1 1 1 1 1 1 1 2 1 1 1 1 2 1 1 2 1 2 3 1 3 3 1 1 1

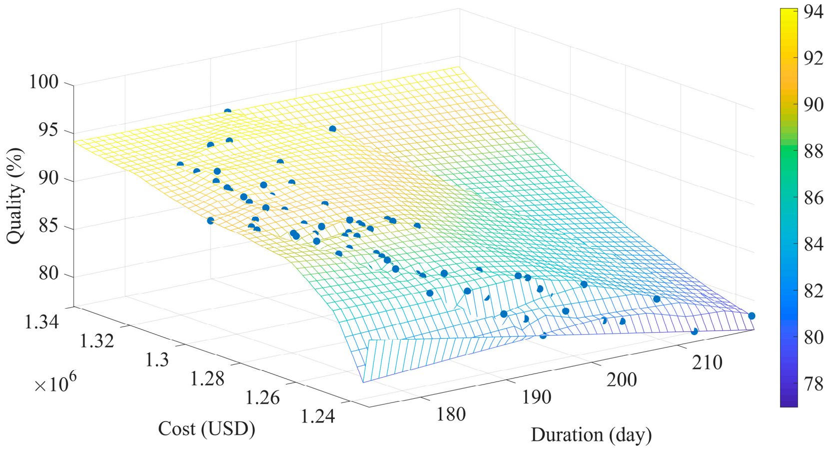

Figure 4. Pareto front for 29-activity TCQTP.

4.2.3. The 63-Activity Problem

The largest benchmark problem that includes 63 activities is based on the time–cost trade-off problem, which was originally introduced by Sonmez and Bettemir [37]. Similar to the 29-actvity TCTP, this project did not include any quality data and was studied the trade-off only between the time and cost of the project. In the present work, however, this problem has been modified, and the execution modes are incorporated with quality performances. Akin to the 29-activity TCQTP, quality performance values are determined such that the execution modes of each activity remain non-dominated against each other. The activity table summarizing the activity weights, logical relationships, and time–cost–quality alternatives is given in Table 7. This TCQTP is examined under two cases with different indirect cost rates of USD 2300/day and USD 3500/day.

Table 7. Activity table for 63-activity TCQTP.

Act.	Precedence Relations	Activity Weight (%)	Duration (Day)	Cost (USD)	Quality (%)	Act.	Precedence Relations	Activity Weight (%)	Duration (Day)	Cost (USD)	Quality (%)
1	-	2	14	3750	67.80	34	28FS, 30FS	2	74	89,250	65.90
			12	4250	75.80				71	93,800	73.90
			10	5400	87.80				66	99,750	81.90
			9	6250	98.80				62	105,100	89.90
2	-	3	21	11,250	62.30				57	114,250	96.90
			18	14,800	70.30	35	24FS, 27FS, 29FS	4	138	183,000	67.80
			17	16,200	82.30				126	201,500	75.80
			15	19,650	93.30				115	238,000	83.80
3	-	1	24	22,450	61.90				103	283,750	91.80
			22	24,900	69.90				98	297,500	98.80
			19	27,950	81.90	36	24FS	1	54	47,500	66.90
			17	31,650	92.90				49	50,750	74.90

4	-	3	19	17,800	64.60
			17	19,400	83.60
			15	21,600	94.60
5	-	2	28	31,180	62.00
			26	34,200	70.00
			23	38,250	82.00
			21	41,400	93.00
6	1FS	1	44	54,260	64.60
			42	58,450	72.60
			38	63,225	84.60
			35	68,150	95.60
7	1FS	2	39	47,600	63.30
			36	50,750	71.30
			33	54,800	83.30
			30	59,750	94.30
8	2FS	1	52	62,140	63.70
			47	69,700	71.70
			44	72,600	83.70
			39	81,750	94.70
9	3FS	1	63	72,750	64.50
			59	79,450	72.50
			55	86,250	80.50
			51	91,500	88.50
			49	99,500	95.50
10	4FS	2	57	66,500	63.50
			53	70,250	71.50
			50	75,800	79.50
			46	80,750	87.50
			41	86,450	94.50
11	5FS	1	63	83,100	61.80
			59	89,450	69.80
			55	97,800	77.80
			50	104,250	85.80
			45	112,400	92.80
12	6FS	1	68	75,500	61.50
			62	82,000	69.50
			58	87,500	77.50
			53	91,800	85.50
			49	96,550	92.50
13	7FS	2	40	34,250	67.90
			37	38,500	75.90
			33	43,950	87.90
			31	48,750	99.90
14	8FS	4	33	52,750	61.60
			30	58,450	69.60
			27	63,400	81.60
			25	66,250	93.60
15	9FS	2	47	38,140	64.30
			40	41,500	72.30
			35	47,650	84.30
			32	54,100	96.30
16	9FS, 10FS	1	75	94,600	62.50
			70	101,250	70.50
			66	112,750	78.50
			61	124,500	86.50
			57	132,850	93.50
17	10FS	2	60	78,450	66.30

			42	56,800	82.90
			38	62,750	90.90
			33	68,250	97.90
37	31FS	1	34	22,500	65.20
			32	24,100	73.20
			29	26,750	81.20
			27	29,800	89.20
			24	31,600	96.20
38	32FS	2	51	61,250	62.00
			47	65,800	70.00
			44	71,250	78.00
			41	76,500	86.00
			38	80,400	93.00
39	33FS	3	67	81,150	65.70
			61	87,600	73.70
			57	92,100	81.70
			52	97,450	89.70
			49	102,800	96.70
40	34FS	1	41	45,250	65.10
			39	48,400	73.10
			36	51,200	81.10
			33	54,700	89.10
			31	58,200	96.10
41	35FS	2	37	17,500	63.10
			31	21,200	71.10
			27	26,850	83.10
			23	32,300	94.10
42	36FS	1	44	36,400	62.00
			41	39,750	70.00
			38	42,800	78.00
			32	48,300	86.00
			30	50,250	93.00
43	36FS	1	75	66,800	67.50
			69	71,200	75.50
			63	76,400	83.50
			59	81,300	91.50
			54	86,200	98.50
44	37FS	1	82	102,750	64.10
			76	109,500	72.10
			70	127,000	80.10
			66	136,800	88.10
			63	146,000	95.10
45	39FS	2	59	84,750	68.70
			55	91,400	76.70
			51	101,300	84.70
			47	126,500	92.70
			43	142,750	99.70
46	39FS	2	66	94,250	63.40
			63	99,500	71.40
			59	108,250	79.40
			55	118,500	87.40
			50	136,000	94.40
47	40FS	1	54	73,500	63.30
			51	78,500	71.30
			47	83,600	79.30
			44	88,700	87.30
			41	93,400	94.30

			55	84,500	74.30	48	42FS	1	41	36,750	66.50
			49	91,250	87.30				39	39,800	74.50
			47	94,640	96.30				37	43,800	82.50
18	10FS, 11FS	2	81	127,150	64.90				34	48,500	90.50
			73	143,250	72.90				31	53,950	97.50
			66	154,600	85.90	49	38FS, 41FS, 44FS	1	173	267,500	62.10
			61	161,900	94.90				159	289,700	70.10
19	11FS	3	36	82,500	66.30				147	312,000	78.10
			34	94,800	85.30				138	352,500	86.10
			30	101,700	96.30				121	397,750	93.10
20	12FS	2	41	48,350	63.30	50	45FS	2	101	47,800	66.80
			37	53,250	71.30				74	61,300	74.80
			34	59,450	85.30				63	76,800	88.80
			32	66,800	94.30				49	91,500	98.80
21	13FS	1	64	85,250	64.80	51	46FS	1	83	84,600	62.40
			60	92,600	72.80				77	93,650	70.40
			57	99,800	80.80				72	98,500	78.40
			53	107,500	88.80				65	104,600	86.40
			49	113,750	95.80				61	113,200	93.40
22	14FS	1	58	74,250	61.70	52	47FS	1	31	23,150	64.30
			53	79,100	69.70				28	27,600	72.30
			50	86,700	77.70				26	29,800	80.30
			47	91,500	85.70				24	32,750	88.30
			42	97,400	92.70				21	35,200	95.30
23	15FS	2	43	66,450	65.40	53	43FS, 48FS	1	39	31,500	64.40
			41	69,800	73.40				36	34,250	72.40
			37	75,800	81.40				33	37,800	80.40
			33	81,400	89.40				29	41,250	88.40
			30	88,450	96.40				26	44,600	95.40
24	16FS	1	66	72,500	62.00	54	49FS	3	23	16,500	67.80
			62	78,500	70.00				22	17,800	75.80
			58	83,700	78.00				21	19,750	83.80
			53	89,350	86.00				20	21,200	91.80
			49	96,400	93.00				18	24,300	98.80
25	17FS	1	54	66,650	66.30	55	52FS, 53FS	1	29	23,400	66.20
			50	70,100	74.30				27	25,250	74.20
			47	74,800	82.30				26	26,900	82.20
			43	79,500	90.30				24	29,400	90.20
			40	86,800	97.30				22	32,500	97.20
26	18FS	1	84	93,500	63.80	56	50FS, 53FS	1	38	41,250	63.20
			79	102,500	71.80				35	44,650	71.20
			73	111,250	79.80				33	47,800	79.20
			68	119,750	87.80				31	51,400	87.20
			62	128,500	94.80				29	55,450	94.20
27	20FS	3	67	78,500	67.50	57	51FS, 54FS	2	41	37,800	68.40
			60	86,450	75.50				38	41,250	76.40
			57	89,100	83.50				35	45,600	84.40
			56	91,500	91.50				32	49,750	92.40
			53	94,750	98.50				30	53,400	99.40
28	21FS	1	66	85,000	64.00	58	52FS	1	24	12,500	65.00
			63	89,750	72.00				22	13,600	73.00
			60	92,500	80.00				20	15,250	81.00
			58	96,800	88.00				18	16,800	89.00
			54	100,500	95.00				16	19,450	96.00
29	22FS	1	76	92,700	64.80	59	55FS	1	27	34,600	66.70
			71	98,500	72.80				24	37,500	74.70

			67	104,600	80.80				22	41,250	82.70
			64	109,900	88.80				19	46,750	90.70
			60	115,600	95.80				17	50,750	97.70
30	23FS	1	34	27,500	61.80	60	56FS	1	31	28,500	67.60
			32	29,800	69.80				29	30,500	75.60
			29	31,750	77.80				27	33,250	83.60
			27	33,800	85.80				25	38,000	91.60
			26	36,200	92.80				21	43,800	98.60
31	19FS, 25FS	1	96	145,000	64.60	61	56FS, 57FS	1	29	22,500	67.10
			89	154,800	72.60				27	24,750	75.10
			83	168,650	80.60				25	27,250	83.10
			77	179,500	88.60				22	29,800	91.10
			72	189,100	95.60				20	33,500	98.10
32	26FS	1	43	43,150	66.80	62	60FS	3	25	38,750	68.40
			40	48,300	74.80				23	41,200	76.40
			37	51,450	82.80				21	44,750	84.40
			35	54,600	90.80				19	49,800	92.40
			33	61,450	97.80				17	51,100	99.40
33	26FS	1	52	61,250	67.40	63	61FS	1	27	9500	64.60
			49	64,350	75.40				26	9700	72.60
			44	68,750	83.40				25	10,100	80.60
			41	74,500	91.40				24	10,800	88.60
			38	79,500	98.40				22	12,700	95.60

The performance of the present GA over the 63-activity problem with IC = USD 2300/day and IC = USD 3500/day is displayed in Tables 8 and 9, respectively. For the sake of brevity and clarity, only a small number of the located Pareto solutions are presented in these tables. For the complete set of Pareto solutions, readers are referred to Abdulsattar [35]. For the daily indirect cost rate of USD 2300, the multi-objective GA, with its parameters set as per Table 1, was able to achieve 222 non-dominated solutions within a period of 2411 s. The Pareto optimal solutions resulted in, for the first case, ranges from 534 to 622 for the duration, USD 5,691,760 to USD 6,185,040 for the cost, and 75.19% to 88.54% for the quality performance. For the daily indirect cost rate of USD 3500, on the other hand, the GA using the same parameter values was able to achieve 144 non-dominated solutions within a period of 3980 s. The non-dominated solutions achieved, for the second case, ranges from 532 to 610 for the duration, USD 6,417,440 to USD 6,824,250 for the cost, and 76.25% to 87.85% for the quality performance. The entire set of Pareto front solutions for each of the cases are demonstrated graphically in Figures 5 and 6. The trade-off among the main three project objectives is clearly visible in these figures. The results of the present method can likewise help decision makers evaluate several potential project performance plans.

Table 8. Selected Pareto solutions for 63-activity TCQTP with IC = USD 2300/day.

Sol. No.	Dur. (Day)	Cost (USD)	Quality (%)	Mode Selection
1	534	6,059,140	83.15	1 1 4 1 2 1 1 4 5 5 1 4 1 1 1 2 4 2 3 4 5 5 3 2 5 3 3 3 3 3 3 3 3 2 5 3 4 3 1 2 4 4 2 4 4 4 3 1 5 4 5 5 5 5 4 5 5 5 4 5 5 5 5
24	547	6,165,720	87.57	4 2 4 3 1 4 2 2 3 5 3 3 4 4 1 5 3 3 3 3 2 4 4 2 5 3 3 3 5 3 3 5 3 4 5 2 2 4 4 4 1 5 3 4 3 5 4 3 5 4 3 5 5 5 5 5 4 5 5 5 4 4 5
40	552	5,976,565	85.64	3 4 4 3 4 3 3 4 1 3 3 3 4 4 2 4 4 4 2 3 1 3 2 1 2 5 5 2 1 3 5 3 1 3 4 4 2 4 5 2 2 4 5 3 1 3 2 3 5 1 2 2 3 5 5 2 5 5 2 1 5 5 5
64	561	6,072,075	86.76	1 4 4 2 2 3 4 3 1 5 5 3 4 4 4 4 1 3 3 2 2 1 4 2 4 1 5 5 5 3 5 3 2 5 3 4 2 3 4 3 4 4 4 4 2 4 4 5 5 4 1 2 2 5 4 3 5 5 5 2 3 5 2

115	573	5,846,940	81.93	1 4 4 3 4 4 1 4 1 4 1 1 1 4 1 5 1 2 3 4 2 4 1 4 4 5 3 5 1 3 1 1 3 4 2 3 5 3 3 2 3 5 2 2 2 1 1 1 5 2 2 5 3 5 5 3 5 5 3 2 5 2 4
145	582	6,116,850	88.16	1 4 1 3 4 1 4 2 1 5 1 5 4 3 4 2 4 3 3 4 2 1 2 5 4 3 5 3 3 1 2 3 5 3 3 3 3 3 5 4 4 2 4 5 5 4 4 4 4 4 2 5 5 5 5 3 5 5 5 5 5 5 4
189	595	5,749,135	79.20	1 1 1 3 1 3 2 3 1 4 3 1 2 4 1 1 4 2 2 1 1 2 1 4 2 3 3 2 2 2 3 1 4 3 3 2 3 2 2 4 4 5 2 1 1 1 1 4 3 2 1 5 4 5 5 5 5 3 1 5 5 3 4
205	604	5,896,965	84.62	4 4 1 2 3 3 4 4 5 5 1 2 3 4 4 1 4 3 3 3 2 1 4 4 5 2 4 5 1 3 1 1 3 2 4 4 5 2 4 4 4 2 4 2 1 4 1 2 1 1 2 4 1 5 5 1 5 2 5 3 5 1 5
222	622	5,724,140	78.78	2 4 3 2 2 2 2 2 3 1 2 3 1 4 1 1 2 2 2 1 1 1 1 4 1 2 5 1 5 1 2 1 5 2 1 1 3 2 5 2 2 3 1 1 2 4 2 5 3 1 3 1 1 5 1 3 5 5 3 2 4 5 5

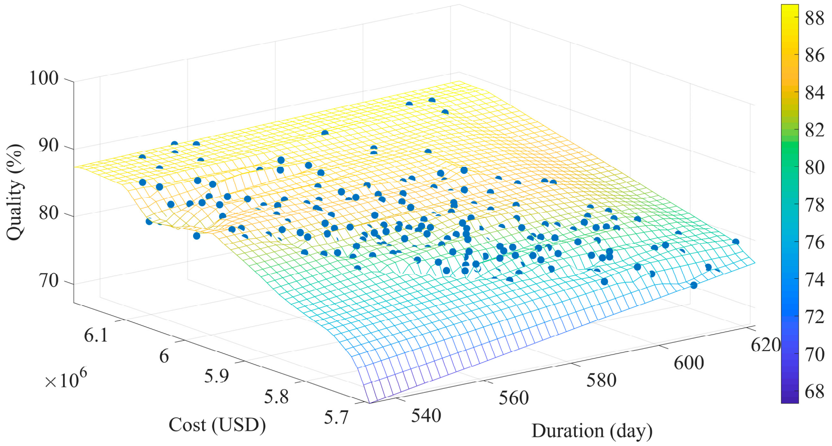

Figure 5. Pareto front for 63-activity TCQTP with IC = USD 2300/day.

Table 9. Selected Pareto solutions for 63-activity TCQTP with IC = USD 3500/day.

Sol. No.	Dur. (day)	Cost (USD)	Quality (%)	Mode Selection
1	532	6,687,815	85.25	2 4 4 1 4 3 1 3 3 5 5 5 1 4 1 4 3 1 2 4 2 3 3 2 5 1 2 4 5 5 5 3 3 3 5 2 3 3 4 5 4 3 5 4 4 4 3 1 5 2 3 3 5 5 4 4 5 5 2 4 5 5 1
8	540	6,634,605	84.43	4 2 3 3 3 3 3 3 3 5 1 3 4 1 1 2 4 2 2 2 1 4 1 2 3 2 5 3 4 1 4 5 2 3 5 3 4 4 5 1 4 2 1 4 4 4 4 3 5 3 4 5 4 5 2 4 5 5 1 3 4 3 5
45	554	6,779,350	87.17	3 4 2 3 4 4 3 2 2 5 4 5 2 3 4 1 1 4 3 1 3 5 3 4 5 1 5 2 3 3 5 4 5 3 5 3 4 2 5 5 2 3 3 4 3 4 4 3 5 4 4 5 3 5 3 3 5 5 3 2 3 4 5
72	564	6,554,475	82.87	3 3 2 3 4 3 4 3 2 3 1 4 3 4 2 1 2 3 1 2 1 2 4 3 5 1 3 5 1 5 2 1 4 3 3 2 3 2 5 1 4 1 2 5 4 1 2 1 5 1 4 3 4 5 5 4 5 2 3 5 5 3 5
95	573	6,481,880	79.65	3 1 1 3 3 4 2 2 1 3 1 1 4 1 1 2 4 2 1 2 2 4 2 3 2 2 3 3 4 3 3 1 3 3 3 3 5 2 3 1 4 2 2 1 3 4 1 4 5 1 2 4 2 5 2 2 5 5 3 2 3 5 5
123	588	6,539,690	83.00	3 3 2 3 3 4 3 1 2 3 3 2 4 4 4 2 3 1 2 4 1 4 2 3 5 1 1 1 4 2 2 1 2 4 3 4 4 3 4 3 4 1 3 3 2 3 5 3 3 2 1 1 5 4 1 5 4 2 3 4 5 4 5
125	590	6,505,740	81.70	3 3 3 3 4 2 2 2 1 4 1 1 1 4 3 2 4 2 2 1 4 1 1 2 2 1 5 2 4 3 2 1 5 2 3 3 5 5 2 4 4 4 2 3 1 2 3 1 4 1 1 2 4 5 5 1 4 3 2 5 3 5 3
138	602	6,420,700	76.25	2 4 1 3 4 1 2 3 1 1 1 1 1 1 1 2 1 1 1 2 1 2 1 2 3 2 2 3 3 1 4 3 1 4 3 1 3 2 4 2 3 5 1 1 1 1 4 4 4 1 1 2 4 4 5 1 5 2 3 5 3 1 5
144	610	6,433,510	77.09	1 1 3 1 1 1 1 1 1 1 4 1 1 3 1 2 4 1 1 4 3 2 1 2 2 1 5 4 3 5 2 3 3 2 2 3 1 3 1 3 3 4 4 2 1 2 1 4 3 1 4 1 3 5 5 4 5 3 2 3 5 5 5

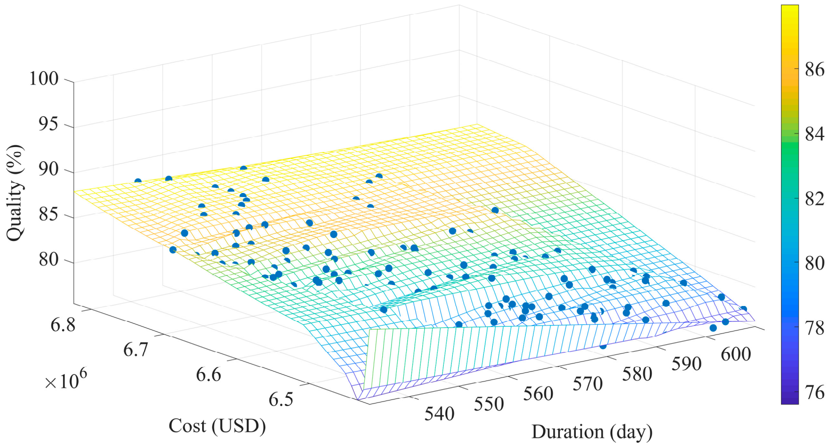

Figure 6. Pareto front for 63-activity TCQTP with IC = USD 3500/day.

4.2.4. The 447-Activity Problem

Owing to the limited number of test problems in the realm of the TCQTP, in this study, an actual construction project with properly overlapped activities is employed to develop the largest multi-objective TCQT problem yet. An actual 25-storey residential building project with over four hundred activities and generalized precedence relationships is used to generate a 447-activity TCQTP. The largest problem is based on the time–cost trade-off problem that was originally introduced by Aminbakhsh and Ahmed [38]. Similar to the 29- and 63-actvity TCQTPs mentioned earlier, this project has been extended in this study to include quality performance for each execution mode. Quality performance values are assigned such that the execution modes for every activity remain non-dominated among each other. The activity table summarizing the activity weights, logical relationships, and time–cost–quality alternatives is given in Table A1. This TCQTP is examined with an indirect cost rate of USD 1188/day, a delay penalty of USD 50,000/day, and a desired completion duration of 684 days.

The performance of the current GA over the largest practiced TCQTP is displayed in Table 10. For the sake of brevity and clarity, only a summary of the Pareto solutions is provided in this table. The multi-objective GA was able to achieve 119 non-dominated solutions within a period of 8293 s. The approximate Pareto front spreads over a range from 635 to 761 for the duration, USD 16,619,584.63 to USD 22,231,005.16 for the cost, and 82.50% to 86.82% for the quality performance. The complete Pareto front is demonstrated graphically in Figure 7. As shown in this figure, the solutions primarily fall within a region where durations are less than 700 days. This concentration of solutions can potentially be attributed to the high rate of daily indirect costs, which leads to a significant increase in the total cost when a deadline is missed, resulting in the domination of solutions with longer durations.

Table 10. Selected Pareto solutions for 447-activity TCQTP.

Sol. No.	Dur. (Day)	Cost (USD)	Quality (%)	Mode Selection
1	635	17,284,797.41	84.60	1 1 1 2 2 2 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 2 2 2 2 2 2 1 2 2 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 1 2 2 1 1 1 1 1 1 1 3 3 3 3 3 3 3 3 1 2 1 1 1 1 1 1 3 3 3 3 3 1 1 1 1 3 1 3 3 1 1 1 1 2 1 1 2 1 2 2 2 2 2 2 1 1 1 1 1 1 1 1 3 1 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1 1 1 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 1 1 1 2 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1 1 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1 1 1 1 2 1 2 3 3 3 3 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
66	665	16,974,798.89	84.29	1 1 1 1 2 2 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 2 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 2 2 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 1 1 1 1 1 1 1 1 1 3 3 3 3 3 3 3 3 1 1 1 1 1 1 1 1 2 3 3 3 3 1 1 1 1 3 1 3 3 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 1 1 1 1 1 1 1 1 3 1 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1 1 1 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1 1 1 1 1 1 2 3 2 3 2 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
113	684	16,619,584.63	82.50	1 1 1 1 1 1 1 1 1 1 1 1 2 2 1 1 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 1 1 1 2 2 1 1 1 1 2 2 1 1 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 2 1 1 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 3 1 2 2 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 1 1 1 1 1 1 1 1 3 1 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1 1 1 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1 1 1 1 1 1 2 3 1 3 2 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
119	761	22,231,005.16	86.82	1 1 1 1 2 2 2 2 1 2 1 2 1 2 1 2 2 1 2 2 2 1 2 2 1 2 2 2 2 1 2 2 2 1 2 2 1 1 1 1 1 2 2 2 2 2 2 1 2 1 2 1 1 2 1 1 1 1 2 2 2 2 1 2 2 1 1 2 2 2 2 1 2 2 2 1 1 1 2 2 2 2 1 2 1 1 2 2 2 2 2 2 2 2 1 2 2 1 1 2 1 1 2 1 2 1 1 1 2 2 1 2 1 2 2 1 1 1 2 2 1 1 2 1 1 2 1 2 2 2 2 1 2 2 1 1 1 1 2 2 2 2 2 1 2 2 1 1 1 2 1 1 2 1 2 2 1 2 1 2 2 2 1 2 1 1 2 2 2 3 1 3 2 1 3 2 3 3 2 3 3 3 2 3 3 1 3 2 1 1 1 2 2 3 3 2 3 2 1 2 3 3 2 2 3 3 1 1 2 3 1 2 2 1 2 1 1 2 3 2 2 1 3 3 2 3 3 2 2 3 3 1 2 2 3 2 1 3 2 2 2 2 2 1 3 2 3 2 3 1 3 3 2 3 2 2 2 3 3 3 2 1 3 3 3 3 3 2 2 3 2 1 1 1 2 3 3 2 1 1 1 3 1 3 2 3 2 1 3 3 2 2 3 1 3 2 3 2 3 1 2 1 2 2 2 1 2 1 2 1 2 2 2 1 2 2 2 1 1 2 2 2 1 2 2 1 2 2 1 2 2 2 2 1 2 2 2 2 2 1 2 1 2 2 1 1 1 2 1 2 2 1 2 2 2 1 2 2 1 2 2 2 1 2 1 2 2 2 2 1 1 2 1 2 2 2 2 2 2 2 1 2 1 2 2 1 2 1 2 2 2 2 2 1 1 2 2 1 2 2 1 1 1 1 3 1 1 2 1 1 1 1 3 3 3 3 1 3 1 2 1 1 3 1 1 1 3 2 2 1 1 3 3 3 2 3 2 2 1 2 1 1 3 2 1 1 1

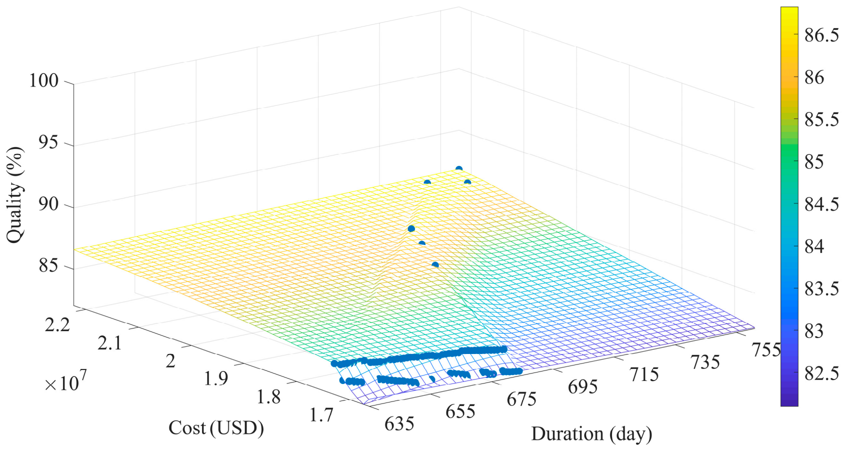

Figure 7. Pareto front for 447-activity TCQTP.

5. Conclusions

Through unique public or private bids, governments and stakeholders naturally desire to achieve reasonable prices with minimum possible makespans and the best quality for their projects. Evidently, weighing the several bid offers and coming up with an optimal decision can pose challenges for the decision makers. The evaluation of the bids and selection of the right contractor is a demanding decision process that can have a substantial impact on the success of the project. Therefore, decision makers should be presented with tools that could provide them with the opportunity to examine the possible consequences of the decisions they face and help them strike a proper balance among the conflicting project objectives of time, cost, and quality. In this regard, a genetic algorithm-based method is presented in this study, which aims to assist in the selection of the best compromise solution by locating the Pareto fronts for the projects. This method achieves the Pareto fronts by concurrently minimizing the time and cost while maximizing the quality of the project.

On the other hand, in real-life projects, activities are frequently overlapped to reduce the unwanted idle times and expedite the project completion time. This is facilitated by the use of possible dependencies in activity relationships (i.e., Start to Start, Start to Finish, Finish to Start, and Finish to Finish) and lag/lead times. The proposed method is able to capture and unravel any of such precedence relationships, a feature that emphasizes the practical relevance of this research. In order to demonstrate the applicability and to evaluate the effectiveness of the proposed model, it is used for the solutions of four different TCQT problems, three of which are generated within the context of this study. The practiced instances include a small benchmark TCQTP with 18 activities taken from the literature in addition to more complex 29- and 63-activity TCQ problems produced herein based on existing 29- and 63-activity time–cost trade-off problems, respectively. The last and largest problem is based on an actual large-scale time–cost trade-off with 447 activities that has been extended to accommodate quality performance values for every execution mode. The results obtained reveal that the presented method can achieve a large number of high-quality Pareto front solutions, and it could be a robust alternative for solving real-world TCQT optimization problems. The proposed model is distinguished from the previous models not only due to the speed of the model in finding non-dominated solutions by the dynamic elimination of the dominated ones, but also because of the diversity and complexity of the practiced test examples. To the best of the authors' knowledge, only a few of the studies have focused their attention on medium- to large-scale time–cost–quality trade-off problems with generalized precedence relationships. It is also expected that the newly introduced complex projects would provide a basis for future studies in this field for comparison purposes, as this knowledge area is still in lack of large benchmark examples. It is anticipated that this work will offer an alternate approach to tackling the TCQTP and will help practitioners and researchers analyze and plan construction projects more effectively. It will help decision makers identify the best options for completing a project within a given budget and deadline with the highest quality, obtaining the lowest cost for a given deadline and quality expectation, or obtaining the shortest timespan for a given budget and quality expectation.

Nevertheless, the challenges associated with the objective evaluation of the quality of each execution alternative for the project activities can be regarded as a limitation of the current study. The large-scale problems introduced in this study accommodate deterministic data with quantifiable activity weights and quality performance values. This may entail methodological limitations for representing construction projects, since in practice, linguistic terms due to uncertainties and subjectivity are often used to evaluate quality performance. Research focusing on the generation of large-scale TCQTPs using realistic quality data would enable a better examination of the performances of the optimization methods. Likewise, further research is required to develop an optimization model to stochastic TCQT data. Furthermore, similar to many evolutionary algorithms, the computational efficiency of the proposed method over high dimensional projects including thousands of activities is of practical concern. Hence, incorporating cutting-edge methods like parallel computing into the current approach is an intriguing avenue for further study.

Additionally, further research taking into account additional objectives that are frequently encountered in construction management, such as work continuity, safety, sustainability, and environmental concerns, is necessary. It also holds interesting potential in integrating the proposed model into a software package with a well-designed user interface to facilitate decision making by presenting the alternative execution plans in a more comprehensible format. The relevance of the alternative techniques in the broader landscape of project management should also be acknowledged. For instance, multi-criteria decision making (MCDM) frameworks offer valuable insights into decision-making processes, which could complement the optimization process by providing additional perspectives on project prioritization. Simulation techniques along with risk management methodologies, which are pivotal in assessing project uncertainties, are another aspect that could be further explored. The consideration of agile and lean practices for the future expansion of the model could also be beneficial for enhancing project flexibility in dynamic project environments.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1 presents the activity table summarizing the activity weights, logical relationships, and time–cost–quality alternatives for the actual 25-storey residential building project with 447 activities.

Table A1. Activity table for 447-activity TCQTP.

Act.	Precedence Relations	Activity Weight (%)	Duration (Day)	Cost (USD)	Quality (%)	Act.	Precedence Relations	Activity Weight (%)	Duration (Day)	Cost (USD)	Quality (%)
1	-	-	-	-	-	233	232FS	0.4	6	7043.60	73.10
2	1FS	0.3	3	229,523.71	93.00				5	7109.60	83.10
3	2FS	0.3	3	382,500.00	96.50				4	7769.00	96.10
4	1FS	0.3	8	698,750.00	82.30	234	233FS	0.3	6	7043.60	69.40
			7	758,916.60	95.30				6	7109.60	79.40
5	4FS	0.2	1	42,430.00	83.40				4	7769.00	92.40
			1	47,044.64	96.40	235	234FS	0.1	6	7043.60	68.20
6	5FS	0.3	1	42,430.00	78.80				6	7109.60	78.20
			1	47,044.64	91.80				4	7769.00	91.20
7	6FS	0.3	1	42,430.00	80.40	236	235FS	0.2	6	7043.60	69.60
			1	47,044.64	93.40				6	7109.60	79.60
8	7FS	0.4	1	42,430.00	81.70				4	7769.00	92.60
			1	47,044.64	94.70	237	236FS	0.2	6	7043.60	66.60
9	6FS	0.3	6	57,510.00	83.80				6	7109.60	76.60
			5	62,707.91	96.80				4	7769.00	89.60
10	8FS	0.1	6	57,510.00	83.30	238	237FS	0.3	6	7043.60	67.50
			5	62,707.91	96.30				6	7109.60	77.50
11	9FS	0.2	1	17,445.00	76.50				4	7769.00	90.50
			1	19,262.89	89.50	239	238FS	0.3	6	7043.60	71.40
12	11FS	0.2	1	17,445.00	78.80				6	7109.60	81.40
			1	19,292.89	91.80				4	7769.00	94.40
13	10FS	0.3	1	17,445.00	78.40	240	239FS	0.2	6	7043.60	69.30
			1	19,292.89	91.40				6	7109.60	79.30
14	13FS	0.2	1	17,445.00	78.50				4	7769.00	92.30
			1	19,292.89	91.50	241	240FS	0.1	6	7043.60	71.50
15	12FS	0.1	6	48,641.28	77.20				6	7109.60	81.50
			5	53,023.90	90.20				4	7769.00	94.50
16	14FS	0.3	6	48,641.28	78.20	242	241FS	0.2	6	7043.60	67.70
			5	53,023.90	91.20				6	7109.60	77.70
17	15FS	0.3	1	17,443.10	81.20				4	7769.00	90.70
			1	19,016.47	94.20	243	242FS	0.3	2	600.00	67.30
18	17FS	0.3	1	17,443.10	79.10				1	700.00	77.30
			1	19,016.47	92.10				1	799.00	90.30
19	16FS	0.3	1	17,443.10	77.40	244	1FS	0.1	1	100.00	94.10
			1	19,016.47	90.40	245	222FS	0.1	6	22,905.12	70.40
20	19FS	0.1	1	17,443.10	77.40				5	24,574.32	80.40
			1	19,016.47	90.40				4	31,525.94	93.40
21	18FS	0.2	6	49,553.17	79.80	246	245FS	0.3	6	22,905.12	68.00
			5	53,793.56	92.80				5	24,574.32	78.00
22	20FS	0.2	6	49,553.17	83.10				4	31,525.94	91.00
			5	53,793.56	96.10	247	246FS	0.2	6	22,905.12	69.20
23	21FS	0.2	1	17,443.16	77.30				5	24,574.32	79.20
			1	18,884.56	90.30				4	31,525.94	92.20
24	23FS	0.3	1	17,443.16	80.20	248	247FS	0.1	6	22,905.12	67.00
			1	18,884.56	93.20				5	24,574.32	77.00
25	22FS	0.3	1	17,443.16	81.80				4	31,525.94	90.00
			1	18,884.56	94.80	249	248FS	0.2	6	22,905.12	69.20
26	25FS	0.1	1	17,443.16	80.60				5	24,574.32	79.20
			1	18,884.56	93.60				4	31,525.94	92.20
27	24FS	0.3	6	49,553.17	78.30	250	249FS	0.2	6	22,905.12	72.20
			5	53,793.56	91.30				5	24,574.32	82.20
28	26FS	0.3	6	49,553.17	83.60				4	31,525.94	95.20
			5	53,793.56	96.60	251	250FS	0.3	6	22,905.12	70.80

29	27FS	0.4	1	17,443.16	77.20				5	24,574.32	80.80
			1	18,884.56	90.20				4	31,525.94	93.80
30	29FS	0.3	1	17,443.16	82.50	252	251FS	0.3	6	22,905.12	69.30
			1	18,884.56	95.50				5	24,574.32	79.30
31	28FS	0.5	1	17,443.16	76.60				4	31,525.94	92.30
			1	18,884.56	89.60	253	252FS	0.2	6	22,905.12	70.20
32	31FS	0.2	1	17,443.16	82.60				5	24,574.32	80.20
			1	18,884.56	95.60				4	31,525.94	93.20
33	30FS	0.3	6	49,553.17	77.30	254	253FS	0.2	6	22,905.12	71.90
			5	53,793.56	90.30				5	24,574.32	81.90
34	32FS	0.2	6	49,553.17	78.00				4	31,525.94	94.90
			5	53,793.56	91.00	255	254FS	0.3	6	22,905.12	71.30
35	33FS	0.2	1	17,443.16	81.20				5	24,574.32	81.30
			1	18,884.56	94.20				4	31,525.94	94.30
36	35FS	0.3	1	17,443.16	80.90	256	255FS	0.1	6	22,905.12	70.00
			1	18,884.56	93.90				5	24,574.32	80.00
37	34FS	0.3	1	17,443.16	80.60				4	31,525.94	93.00
			1	18,884.56	93.60	257	256FS	0.3	6	22,905.12	67.20
38	37FS	0.3	1	17,443.16	77.50				5	24,574.32	77.20
			1	18,884.56	90.50				4	31,525.94	90.20
39	36FS	0.2	6	49,553.17	83.50	258	257FS	0.2	6	22,905.12	67.60
			5	53,793.56	96.50				6	24,574.32	77.60
40	38FS	0.2	6	49,553.17	81.20				4	31,525.94	90.60
			5	53,793.56	94.20	259	258FS	0.3	6	22,905.12	68.70
41	39FS	0.2	1	17,443.16	78.10				6	24,574.32	78.70
			1	18,884.56	91.10				4	31,525.94	91.70
42	41FS	0.3	1	17,443.16	79.30	260	259FS	0.1	6	22,905.12	69.30
			1	18,884.56	92.30				6	24,574.32	79.30
43	40FS	0.2	1	17,443.16	78.80				4	31,525.94	92.30
			1	18,884.56	91.80	261	260FS	0.3	6	22,905.12	71.80
44	43FS	0.1	1	17,443.16	83.00				6	24,574.32	81.80
			1	18,884.56	96.00				4	31,525.94	94.80
45	42FS	0.3	6	49,553.17	80.20	262	261FS	0.1	6	22,905.12	71.60
			5	53,793.56	93.20				6	24,574.32	81.60
46	44FS	0.2	6	49,553.17	76.70				4	31,525.94	94.60
			5	53,793.56	89.70	263	262FS	0.1	7	22,905.12	72.40
47	45FS	0.1	1	17,443.16	82.60				6	24,574.32	82.40
			1	18,884.56	95.60				4	31,525.94	95.40
48	47FS	0.1	1	17,443.16	77.80	264	263FS	0.3	7	22,905.12	68.20
			1	18,884.56	90.80				6	24,574.32	78.20
49	46FS	0.3	1	17,443.16	82.70				4	31,525.94	91.20
			1	18,884.56	95.70	265	264FS	0.1	7	22,905.12	68.50
50	49FS	0.2	1	17,443.16	80.50				6	24,574.32	78.50
			1	18,884.56	93.50				4	31,525.94	91.50
51	50FS	0.4	6	49,553.17	81.10	266	265FS	0.2	7	22,905.12	67.50
			5	53,793.56	94.10				6	24,574.32	77.50
52	51FS	0.2	6	49,553.17	79.00				4	31,525.94	90.50
			5	53,793.56	92.00	267	266FS	0.3	7	22,905.12	73.00
53	51FS	0.3	1	17,443.16	79.90				6	24,574.32	83.00
			1	18,884.56	92.90				4	31,525.94	96.00
54	53FS	0.1	1	17,443.16	77.90	268	267FS	0.3	7	22,905.12	71.80
			1	18,884.56	90.90				6	24,574.32	81.80
55	52FS	0.2	1	17,443.16	78.70				4	31,525.94	94.80
			1	18,884.56	91.70	269	268FS	0.2	7	22,905.12	73.60
56	55FS	0.1	1	17,443.16	78.00				6	24,574.32	83.60
			1	18,884.56	91.00				4	31,525.94	96.60
57	54FS	0.2	6	49,553.17	80.50	270	269FS	0.2	4	15,000.00	72.30

			5	53,793.56	93.50				3	11,000.00	82.30
58	56FS	0.2	6	49,553.17	81.40				1	21,105.59	95.30
			5	53,793.56	94.40	271	242FS	0.2	25	46,800.00	77.20
59	57FS	0.3	1	17,443.16	80.00				10	52,000.00	90.20
			1	18,884.56	93.00	272	242FS	0.1	12	67,079.25	95.60
60	59FS	0.2	1	17,443.16	79.40	273	1FS	0.1	12	100.00	91.90
			1	18,884.56	92.40	274	272FS-10	0.3	9	5920.00	70.10
61	58FS	0.3	1	17,443.16	78.50				7	6690.00	80.10
			1	18,884.56	91.50				4	7578.24	93.10
62	61FS	0.1	1	17,443.16	80.20	275	274FS	0.2	9	5920.00	72.60
			1	18,884.56	93.20				7	6690.00	82.60
63	60FS	0.2	6	49,553.17	78.30				4	7578.24	95.60
			5	53,793.56	91.30	276	275FS	0.2	9	5920.00	67.50
64	62FS	0.3	6	49,553.17	77.60				7	6690.00	77.50
			5	53,793.56	90.60				4	7578.24	90.50
65	63FS	0.3	1	17,443.16	77.00	277	276FS	0.3	9	5920.00	71.60
			1	18,884.56	90.00				7	6690.00	81.60
66	65FS	0.1	1	17,443.16	83.40				4	7578.24	94.60
			1	18,884.56	96.40	278	277FS	0.3	9	5920.00	72.00
67	64FS	0.2	1	17,443.16	80.10				7	6690.00	82.00
			1	18,884.56	93.10				4	7578.24	95.00
68	67FS	0.3	1	17,443.16	78.90	279	278FS	0.2	9	5920.00	71.80
			1	18,884.56	91.90				7	6690.00	81.80
69	66FS+11	0.3	7	49,553.17	77.90				4	7578.24	94.80
			6	53,793.56	90.90	280	279FS	0.3	9	5920.00	71.60
70	68FS+14	0.1	7	49,553.17	81.80				7	6690.00	81.60
			6	53,793.56	94.80				4	7578.24	94.60
71	69FS	0.2	1	17,443.16	82.20	281	280FS	0.3	9	5920.00	68.50
			1	18,884.56	95.20				7	6690.00	78.50
72	71FS	0.1	1	17,443.16	82.80				4	7578.24	91.50
			1	18,884.56	95.80	282	281FS	0.2	9	5920.00	72.60
73	70FS	0.2	1	17,443.16	77.40				7	6690.00	82.60
			1	18,884.56	90.40				4	7578.24	95.60
74	73FS	0.3	1	17,443.16	81.80	283	282FS	0.1	9	5920.00	67.30
			1	18,884.56	94.80				8	6690.00	77.30
75	72FS+1	0.3	7	49,553.17	79.80				4	7578.24	90.30
			6	53,793.56	92.80	284	283FS	0.2	9	5920.00	70.50
76	74FS+6	0.3	7	49,553.17	80.90				8	6690.00	80.50
			6	53,793.56	93.90				4	7578.24	93.50
77	75FS	0.3	1	17,443.16	81.20	285	284FS	0.3	9	5920.00	73.10
			1	18,884.56	94.20				8	6690.00	83.10
78	77FS	0.3	1	17,443.16	80.00				4	7578.24	96.10
			1	18,884.56	93.00	286	285FS	0.4	9	5920.00	71.00
79	76FS	0.3	1	17,443.16	78.90				8	6690.00	81.00
			1	18,884.56	91.90				4	7578.24	94.00
80	79FS	0.2	1	17,443.16	77.70	287	286FS	0.1	9	5920.00	72.10
			1	18,884.56	90.70				8	6690.00	82.10
81	78FS+4	0.2	7	49,553.17	79.90				4	7578.24	95.10
			6	53,793.56	92.90	288	287FS	0.1	9	5920.00	71.80
82	80FS+4	0.3	7	49,553.17	79.90				8	6690.00	81.80
			6	53,793.56	92.90				4	7578.24	94.80
83	81FS	0.3	1	17,443.16	79.10	289	288FS	0.3	9	5920.00	72.70
			1	18,884.56	92.10				8	6690.00	82.70
84	83FS	0.2	1	17,443.16	77.30				4	7578.24	95.70
			1	18,884.56	90.30	290	289FS	0.2	9	5920.00	67.80
85	82FS	0.1	1	17,443.16	81.90				8	6690.00	77.80
			1	18,884.56	94.90				4	7578.24	90.80

86	85FS	0.2	1	17,443.16	82.00	291	290FS	0.2	9	5920.00	69.00
			1	18,884.56	95.00				9	6690.00	79.00
87	84FS	0.2	7	49,553.17	80.30				4	7578.24	92.00
			6	53,793.56	93.30	292	291FS	0.1	9	5920.00	71.50
88	86FS	0.1	7	49,553.17	81.70				9	6690.00	81.50
			6	53,793.56	94.70				4	7578.24	94.50
89	87FS	0.3	1	17,443.16	78.00	293	292FS	0.1	9	5920.00	67.80
			1	18,884.56	91.00				9	6690.00	77.80
90	89FS	0.1	1	17,443.16	78.10				4	7578.24	90.80
			1	18,884.56	91.10	294	293FS	0.3	9	5920.00	72.70
91	88FS	0.1	1	17,443.16	82.10				9	6690.00	82.70
			1	18,884.56	95.10				4	7578.24	95.70
92	91FS	0.1	1	17,443.16	82.80	295	294FS	0.2	9	5920.00	70.20
			1	18,884.56	95.80				9	6690.00	80.20
93	90FS	0.2	7	49,553.17	82.40				4	7578.24	93.20
			6	53,793.56	95.40	296	295FS	0.2	9	5920.00	69.20
94	92FS	0.1	7	49,553.17	81.30				9	6690.00	79.20
			6	53,793.56	94.30				4	7578.24	92.20
95	93FS	0.2	1	17,443.16	78.00	297	296FS	0.3	9	5920.00	70.30
			1	18,884.56	91.00				9	6690.00	80.30
96	95FS	0.4	1	17,443.16	82.20				4	7578.24	93.30
			1	18,884.56	95.20	298	297FS	0.3	9	5920.00	67.00
97	94FS	0.3	1	17,443.16	82.10				9	6690.00	77.00
			1	18,884.56	95.10				4	7578.24	90.00
98	97FS	0.3	1	17,443.16	76.90	299	298FS	0.2	6	2000.00	71.80
			1	18,884.56	89.90				4	1000.00	81.80
99	96FS	0.3	7	49,553.17	79.20				2	1136.82	94.80
			6	53,793.56	92.20	300	1FS	0.1	12	100.00	95.30
100	98FS	0.3	7	49,553.17	81.40	301	231FS	0.1	2	3305.10	78.90
			6	53,793.56	94.40				1	4265.00	91.90
101	99FS	0.1	1	17,443.16	82.10	302	301FS	0.3	2	3305.10	81.90
			1	18,884.56	95.10				1	4265.00	94.90
102	101FS	0.1	1	17,443.16	81.40	303	302FS	0.1	2	3305.10	79.20
			1	18,884.56	94.40				1	4265.00	92.20
103	100FS	0.2	1	17,443.16	77.80	304	303FS	0.3	2	3305.10	80.70
			1	18,884.56	90.80				1	4265.00	93.70
104	103FS	0.1	1	17,443.16	79.00	305	304FS	0.2	2	3305.10	83.30
			1	18,884.56	92.00				1	4265.00	96.30
105	102FS	0.3	7	49,553.17	81.60	306	305FS	0.2	2	3305.10	82.50
			6	53,793.56	94.60				1	4265.00	95.50
106	104FS	0.1	7	49,553.17	79.50	307	306FS	0.1	2	3305.10	78.60
			6	53,793.56	92.50				1	4265.00	91.60
107	105FS	0.1	1	17,443.16	77.30	308	307FS	0.1	2	3305.10	77.10
			1	18,884.56	90.30				1	4265.00	90.10
108	107FS	0.3	1	17,443.16	79.00	309	308FS	0.3	2	3305.10	83.00
			1	18,884.56	92.00				1	4265.00	96.00
109	106FS	0.4	1	17,443.16	77.30	310	309FS	0.2	2	3305.10	78.60
			1	18,884.56	90.30				1	4265.00	91.60
110	109FS	0.3	1	17,443.16	81.70	311	310FS	0.1	2	3305.10	77.60
			1	18,884.56	94.70				1	4265.00	90.60
111	108FS	0.2	7	49,553.17	79.10	312	311FS	0.3	2	3305.10	78.20
			6	53,793.56	92.10				1	4265.00	91.20
112	110FS	0.3	7	49,553.17	80.20	313	312FS	0.3	2	3305.10	79.20
			6	53,793.56	93.20				1	4265.00	92.20
113	111FS	0.1	1	17,443.16	78.40	314	313FS	0.2	2	3305.10	78.00
			1	18,884.56	91.40				1	4265.00	91.00
114	113FS	0.2	1	17,443.16	80.80	315	314FS	0.1	2	3305.10	80.30

			1	18,884.56	93.80				1	4265.00	93.30
115	112FS	0.1	1	17,443.16	81.10	316	315FS	0.2	2	3305.10	78.90
			1	18,884.56	94.10				1	4265.00	91.90
116	115FS	0.2	1	17,443.16	81.00	317	316FS	0.3	2	3305.10	80.60
			1	18,884.56	94.00				1	4265.00	93.60
117	114FS	0.3	7	49,553.17	79.60	318	317FS	0.1	2	3305.10	78.90
			6	53,793.56	92.60				2	4265.00	91.90
118	116FS	0.2	7	49,553.17	79.30	319	318FS	0.3	2	3305.10	83.10
			6	53,793.56	92.30				2	4265.00	96.10
119	117FS	0.3	1	17,443.16	82.70	320	319FS	0.2	2	3305.10	82.20
			1	18,884.56	95.70				2	4265.00	95.20
120	119FS	0.2	1	17,443.16	77.70	321	320FS	0.3	2	3305.10	81.30
			1	18,884.56	90.70				2	4265.00	94.30
121	118FS	0.3	1	17,443.16	78.60	322	321FS	0.2	2	3305.10	77.50
			1	18,884.56	91.60				2	4265.00	90.50
122	121FS	0.5	1	17,443.16	77.10	323	322FS	0.3	2	3305.10	77.30
			1	18,884.56	90.10				2	4265.00	90.30
123	120FS	0.2	7	49,553.17	77.60	324	323FS	0.1	2	3305.10	82.90
			6	53,793.56	90.60				2	4265.00	95.90
124	122FS	0.3	7	49,553.17	78.90	325	324FS	0.3	2	3305.10	81.10
			6	53,793.56	91.90				2	4265.00	94.10
125	123FS	0.3	1	17,443.16	81.40	326	325FS	0.2	1	100.00	95.40
			1	18,884.56	94.40	327	293FS	0.3	2	7944.00	79.60
126	125FS	0.3	1	17,443.16	78.00				1	9000.00	92.60
			1	18,884.56	91.00	328	327FS	0.3	2	7944.00	76.40
127	124FS	0.3	1	17,443.16	76.70				1	8540.00	89.40
			1	18,884.56	89.70	329	328FS	0.3	2	7944.00	81.00
128	127FS	0.2	1	17,443.16	79.00				1	10,440.00	94.00
			1	18,884.56	92.00	330	329FS	0.2	2	7944.00	79.20
129	126FS	0.1	7	49,553.17	83.10				1	10,440.00	92.20
			6	53,793.56	96.10	331	330FS	0.1	2	7944.00	81.50
130	128FS	0.3	7	49,553.17	77.70				1	10,440.00	94.50
			6	53,793.56	90.70	332	331FS	0.1	2	7944.00	77.70
131	129FS	0.3	1	17,443.16	78.30				1	10,440.00	90.70
			1	18,884.56	91.30	333	332FS	0.1	2	7944.00	82.60
132	131FS	0.2	1	17,443.16	78.40				1	10,440.00	95.60
			1	18,884.56	91.40	334	333FS	0.2	2	7944.00	77.50
133	130FS	0.1	1	17,443.16	83.10				1	10,440.00	90.50
			1	18,884.56	96.10	335	334FS	0.3	2	7944.00	79.80
134	133FS	0.2	1	17,443.16	82.60				1	10,440.00	92.80
			1	18,884.56	95.60	336	335FS	0.3	2	7944.00	81.00
135	132FS	0.2	7	49,553.17	82.10				1	10,440.00	94.00
			6	53,793.56	95.10	337	336FS	0.2	2	7944.00	84.10
136	134FS	0.3	7	49,553.17	82.80				1	10,440.00	97.10
			6	53,793.56	95.80	338	337FS	0.3	2	7944.00	82.00
137	135FS	0.1	1	17,443.16	77.60				1	10,440.00	95.00
			1	18,884.56	90.60	339	338FS	0.3	2	7944.00	79.20
138	137FS	0.2	1	17,443.16	80.20				1	10,440.00	92.20
			1	18,884.56	93.20	340	339FS	0.1	2	7944.00	78.20
139	136FS	0.2	1	17,443.16	76.70				1	10,440.00	91.20
			1	18,884.56	89.70	341	340FS	0.1	2	7944.00	77.00
140	139FS	0.3	1	17,443.16	77.30				1	10,440.00	90.00
			1	18,884.56	90.30	342	341FS	0.3	2	7944.00	80.70
141	138FS	0.1	7	49,553.17	80.30				1	10,440.00	93.70
			6	53,793.56	93.30	343	342FS	0.2	2	7944.00	80.20
142	140FS	0.1	7	49,553.17	81.70				1	10,440.00	93.20
			6	53,793.56	94.70	344	343FS	0.1	2	7944.00	80.60

143	141FS	0.3	1	17,443.16	82.50				1	10,440.00	93.60
			1	18,884.56	95.50	345	344FS	0.1	2	7944.00	79.00
144	143FS	0.2	1	17,443.16	80.60				1	10,440.00	92.00
			1	18,884.56	93.60	346	345FS	0.1	2	7944.00	78.00
145	142FS	0.3	1	17,443.16	81.50				1	10,440.00	91.00
			1	18,884.56	94.50	347	346FS	0.1	2	7944.00	80.20
146	145FS	0.3	1	17,443.16	78.50				1	10,440.00	93.20
			1	18,884.56	91.50	348	347FS	0.2	2	7944.00	82.50
147	144FS	0.3	7	49,553.17	77.40				1	10,440.00	95.50
			6	53,793.56	90.40	349	348FS	0.3	2	7944.00	79.90
148	146FS	0.1	7	49,553.17	82.10				1	10,440.00	92.90
			6	53,793.56	95.10	350	349FS	0.3	2	7944.00	78.90
149	147FS	0.1	1	17,443.16	76.30				1	10,440.00	91.90
			1	18,884.56	89.30	351	350FS	0.1	2	7944.00	80.30
150	149FS	0.2	1	17,443.16	78.20				1	10,440.00	93.30
			1	18,884.56	91.20	352	329FS	0.2	3	4917.00	82.00
151	148FS	0.3	1	17,443.16	80.40				2	6820.00	95.00
			1	18,884.56	93.40	353	352FS	0.2	3	4917.00	82.50
152	151FS	0.1	1	17,443.16	80.20				2	6820.00	95.50
			1	18,884.56	93.20	354	353FS	0.3	3	4917.00	82.80
153	150FS	0.3	7	49,553.17	80.30				2	6820.00	95.80
			6	53,793.56	93.30	355	354FS	0.1	3	4917.00	82.30
154	152FS	0.3	7	49,553.17	80.60				2	6820.00	95.30
			6	53,793.56	93.60	356	355FS	0.2	3	4917.00	78.80
155	153FS	0.3	1	17,443.16	79.50				2	6820.00	91.80
			1	18,884.56	92.50	357	356SF	0.2	3	4917.00	82.60
156	155FS	0.3	1	17,443.16	81.60				2	6820.00	95.60
			1	18,884.56	94.60	358	357FS	0.3	3	4917.00	82.20
157	154FS	0.2	1	17,443.16	79.50				2	6820.00	95.20
			1	18,884.56	92.50	359	358FS	0.3	3	4917.00	78.70
158	157FS	0.3	1	17,443.16	82.50				2	6820.00	91.70
			1	18,884.56	95.50	360	359FS	0.2	3	4917.00	79.20
159	156FS	0.3	7	49,557.17	76.80				2	6820.00	92.20
			6	53,635.81	89.80	361	360FS	0.3	3	4917.00	81.20
160	158FS	0.2	7	49,557.17	80.80				2	6820.00	94.20
			6	53,635.81	93.80	362	361FS	0.3	3	4917.00	80.50
161	160FS	0.3	2	29,723.98	83.20				2	6820.00	93.50
			2	32,075.50	96.20	363	362FS	0.3	3	4917.00	81.90
162	161FS	0.2	2	8579.19	82.50				2	6820.00	94.90
			2	9312.42	95.50	364	363FS	0.2	3	4917.00	82.90
163	1FS	0.2	12	100.00	89.90				2	6820.00	95.90
164	152FS	0.1	3	21,912.00	66.50	365	364FS	0.3	3	4917.00	81.20
			2	38,557.21	76.50				2	6820.00	94.20
			2	42,183.38	89.50	366	365FS	0.2	3	4917.00	76.90
165	164FS	0.3	3	21,912.00	70.70				3	6820.00	89.90
			2	38,557.21	80.70	367	366FS	0.3	3	4917.00	82.00
			2	42,183.38	93.70				3	6820.00	95.00
166	165FS	0.2	3	21,912.00	70.70	368	367FS	0.1	3	4917.00	80.70
			2	38,557.21	80.70				3	6820.00	93.70
			2	42,183.38	93.70	369	368FS	0.3	3	4917.00	79.50
167	166FS	0.2	3	21,912.00	72.10				3	6820.00	92.50
			2	38,557.21	82.10	370	369FS	0.2	3	4917.00	79.80
			2	42,183.38	95.10				3	6820.00	92.80
168	167FS	0.2	3	21,912.00	68.50	371	370FS	0.1	3	4917.00	82.20
			2	38,557.21	78.50				3	6820.00	95.20
			2	42,183.38	91.50	372	371FS	0.3	3	4917.00	81.20
169	168FS	0.3	3	21,912.00	71.50				3	6820.00	94.20

			2	38,557.21	81.50	373	372FS	0.2	3	4917.00	82.80
			2	42,183.38	94.50				3	6820.00	95.80
170	169FS	0.1	3	21,912.00	68.80	374	373FS	0.1	3	4917.00	76.60
			2	38,557.21	78.80				3	6820.00	89.60
			2	42,183.38	91.80	375	374FS	0.3	3	4917.00	80.50
171	170FS	0.4	3	21,912.00	73.80				3	6820.00	93.50
			2	38,557.21	83.80	376	375FS	0.3	3	4917.00	83.40
			2	42,183.38	96.80				3	6820.00	96.40
172	171FS	0.2	3	21,912.00	71.60	377	292FS	0.3	4	45,000.00	80.40
			2	38,557.21	81.60				1	60,000.00	93.40
			2	42,183.38	94.60	378	377FS	0.1	4	45,000.00	79.30
173	172FS	0.2	3	21,912.00	66.90				1	60,000.00	92.30
			2	38,557.21	76.90	379	378FS	0.3	4	33,280.00	79.30
			2	42,183.38	89.90				1	40,000.00	92.30
174	173FS	0.1	3	21,912.00	69.80	380	379FS	0.3	4	33,280.00	80.80
			2	38,557.21	79.80				1	40,000.00	93.80
			2	42,183.38	92.80	381	380FS	0.3	4	33,280.00	79.50
175	174FS	0.2	3	21,912.00	73.00				1	40,000.00	92.50
			3	38,557.21	83.00	382	381FS	0.3	4	33,280.00	79.90
			2	42,183.38	96.00				1	40,000.00	92.90
176	175FS	0.2	3	21,912.00	67.80	383	382FS	0.3	4	33,280.00	80.10
			3	38,557.21	77.80				1	40,000.00	93.10
			2	42,183.38	90.80	384	383FS	0.3	4	33,280.00	76.50
177	176FS	0.1	3	21,912.00	67.10				1	40,000.00	89.50
			3	38,557.21	77.10	385	384FS	0.1	4	33,280.00	79.80
			2	42,183.38	90.10				1	40,000.00	92.80
178	177FS	0.3	3	21,912.00	67.20	386	385FS	0.2	4	33,280.00	80.40
			3	38,557.21	77.20				1	40,000.00	93.40
			2	42,183.38	90.20	387	386FS	0.1	4	33,280.00	81.20
179	178FS	0.1	3	21,912.00	68.70				1	40,000.00	94.20
			3	38,557.21	78.70	388	387FS	0.2	4	33,280.00	80.70
			2	42,183.38	91.70				1	40,000.00	93.70
180	179FS	0.1	3	21,912.00	67.10	389	388FS	0.3	4	33,280.00	76.90
			3	38,557.21	77.10				1	40,000.00	89.90
			2	42,183.38	90.10	390	389FS	0.3	4	33,280.00	77.20
181	180FS	0.3	3	21,912.00	66.60				1	40,000.00	90.20
			3	38,557.21	76.60	391	390FS	0.1	4	33,280.00	77.00
			3	42,183.38	89.60				1	40,000.00	90.00
182	181FS	0.2	3	21,912.00	71.50	392	391FS	0.1	4	33,280.00	82.60
			3	38,557.21	81.50				1	40,000.00	95.60
			3	42,183.38	94.50	393	392FS	0.2	4	33,280.00	79.50
183	182FS	0.2	3	21,912.00	72.10				1	40,000.00	92.50
			3	38,557.21	82.10	394	393FS	0.1	4	33,280.00	81.50
			3	42,183.38	95.10				1	40,000.00	94.50
184	183FS	0.3	3	21,912.00	67.20	395	394FS	0.1	4	33,280.00	78.20
			3	38,557.21	77.20				1	40,000.00	91.20
			3	42,183.38	90.20	396	395FS	0.3	4	33,280.00	83.00
185	184FS	0.1	3	21,912.00	68.30				1	40,000.00	96.00
			3	38,557.21	78.30	397	396FS	0.3	4	33,280.00	83.10
			3	42,183.38	91.30				1	40,000.00	96.10
186	185FS	0.2	3	21,912.00	69.70	398	397FS	0.3	4	33,280.00	82.00
			3	38,557.21	79.70				1	40,000.00	95.00
			3	42,183.38	92.70	399	398FS	0.1	4	33,280.00	77.20
187	186FS	0.2	3	21,912.00	68.00				1	40,000.00	90.20
			3	38,557.21	78.00	400	399FS	0.1	4	33,280.00	80.50
			3	42,183.38	91.00				1	40,000.00	93.50
188	187FS	0.3	3	21,912.00	72.40	401	400FS	0.1	4	33,280.00	79.60

			3	38,557.21	82.40				1	40,000.00	92.60
			3	42,183.38	95.40	402	345FS	0.3	9	15,000.00	91.50
189	162FS+25	0.1	2	2448.00	72.00	403	216FS	0.2	45	196,667.28	80.70
			2	3500.00	82.00				15	470,000.00	93.70
			1	2000.00	95.00	404	403SS	0.1	7	60,000.00	92.40
190	1FS	0.3	12	100.00	93.60	405	403FS	0.2	2	10,050.00	70.50
191	171FS	0.2	4	18,521.41	70.40				1	8040.00	80.50
			4	19,057.98	80.40				1	9601.94	93.50
			4	24,690.00	93.40	406	405FS+7	0.3	5	7825.00	80.60
192	191FS	0.3	4	18,521.41	68.60				2	14,120.50	93.60
			4	19,057.98	78.60	407	406FS	0.3	1	5648.20	90.20
			4	24,690.00	91.60	408	407FS	0.2	1	7907.48	77.30
193	192FS	0.2	4	18,521.41	69.80				1	8040.00	90.30
			4	19,057.98	79.80	409	408FS	0.3	10	21,463.16	81.10
			4	24,690.00	92.80				7	29,900.00	94.10
194	193FS	0.2	4	18,521.41	66.70	410	402FS	0.5	20	85,138.00	80.60
			4	19,057.98	76.70				12	198,360.00	93.60
			4	24,690.00	89.70	411	402FS	0.3	20	27,050.00	77.00
195	194FS	0.1	4	18,521.41	69.20				12	34,048.00	90.00
			4	19,057.98	79.20	412	410FS-3	0.2	25	247,500.00	82.50
			4	24,690.00	92.20				6	306,976.00	95.50
196	195FS	0.3	4	18,521.41	67.40	413	412FS-3	0.2	26	30,600.00	69.30
			4	19,057.98	77.40				20	33,800.00	79.30
			4	24,690.00	90.40				9	36,890.00	92.30
197	196FS	0.2	4	18,521.41	71.90	414	413FS+18	0.2	32	101,395.00	69.40
			4	19,057.98	81.90				27	123,692.00	79.40
			4	24,690.00	94.90				21	153,883.00	92.40
198	197FS	0.3	4	18,521.41	68.80	415	414FS	0.3	25	440,800.00	73.90
			4	19,057.98	78.80				23	431,630.00	83.90
			4	24,690.00	91.80				21	432,925.00	96.90
199	198FS	0.2	4	18,521.41	71.70	416	415FS+15	0.1	130	935,000.00	72.60
			4	19,057.98	81.70				90	977,500.00	82.60
			4	24,690.00	94.70				75	1,094,100.00	95.60
200	199FS	0.2	4	18,521.41	68.00	417	416FS	0.3	8	29,176.00	95.90
			4	19,057.98	78.00	418	415FS	0.2	50	440,800.00	71.50
			4	24,690.00	91.00				45	589,952.00	81.50
201	200FS	0.3	4	18,521.41	69.50				35	661,100.00	94.50
			4	19,057.98	79.50	419	418FS	0.1	5	25,000.00	93.40
			4	24,690.00	92.50	420	240FS	0.3	9	201,600.00	80.40
202	201FS	0.1	5	19,057.98	71.30				8	290,200.00	93.40
			4	18,521.41	81.30	421	412FS+10	0.4	4	10,400.00	91.70
			4	24,690.00	94.30	422	271FS+10	0.3	7	22,880.00	92.10
203	202FS	0.1	5	19,057.98	69.10	423	412FS+10	0.3	10	49,920.00	72.80
			4	18,521.41	79.10				9	41,600.00	82.80
			4	24,690.00	92.10				7	53,000.00	95.80
204	203FS	0.1	5	19,057.98	69.40	424	184FS	0.1	130	112,703.67	70.50
			4	18,521.41	79.40				70	131,807.41	80.50
			4	24,690.00	92.40				60	151,459.76	93.50
205	204FS	0.2	5	19,057.98	72.60	425	184FS	0.3	160	888,013.39	69.00
			4	18,521.41	82.60				130	951,914.72	79.00
			4	24,690.00	95.60				70	1,176,372.33	92.00
206	205FS	0.1	5	19,057.98	68.20	426	184FS	0.2	130	553,826.40	68.30
			4	18,521.41	78.20				70	650,466.67	78.30
			4	24,690.00	91.20				60	744,274.02	91.30
207	206FS	0.3	5	19,057.98	68.50	427	184FS	0.3	130	23,329.84	70.30
			4	18,521.41	78.50				70	27,333.33	80.30
			4	24,690.00	91.50				60	31,352.54	93.30

208	207FS	0.1	6	18,521.41	70.40
			5	19,057.98	80.40
			4	24,690.00	93.40
209	208FS	0.2	6	18,521.41	68.40
			5	19,057.98	78.40
			4	24,690.00	91.40
210	209FS	0.2	6	18,521.41	71.50
			5	19,057.98	81.50
			4	24,690.00	94.50
211	210FS	0.3	6	18,521.41	70.70
			5	19,057.98	80.70
			4	24,690.00	93.70
212	211FS	0.3	6	18,521.41	69.80
			5	19,057.98	79.80
			4	24,690.00	92.80
213	212FS	0.3	6	18,521.41	67.70
			5	19,057.98	77.70
			4	24,690.00	90.70
214	213FS	0.1	6	18,521.41	67.30
			5	19,057.98	77.30
			4	24,690.00	90.30
215	214FS	0.3	6	18,521.41	67.20
			5	19,057.98	77.20
			4	24,690.00	90.20
216	189FS	0.2	4	3000.00	69.00
			3	4000.00	79.00
			2	3000.00	92.00
217	1FS	0.2	27	100.00	94.80
218	192FS	0.3	6	7043.60	68.50
			5	7109.60	78.50
			4	7769.00	91.50
219	218FS	0.3	6	7043.60	69.10
			5	7109.60	79.10
			4	7769.00	92.10
220	219FS	0.3	6	7043.60	72.10
			5	7109.60	82.10
			4	7769.00	95.10
221	220FS	0.3	6	7043.60	71.50
			5	7109.60	81.50
			4	7769.00	94.50
222	221FS	0.2	6	7043.60	67.50
			5	7109.60	77.50
			4	7769.00	90.50
223	222FS	0.2	6	7043.60	67.30
			5	7109.60	77.30
			4	7769.00	90.30
224	223FS	0.2	6	7043.60	71.50
			5	7109.60	81.50
			4	7769.00	94.50
225	224FS	0.3	6	7043.60	72.30
			5	7109.60	82.30
			4	7769.00	95.30
226	225FS	0.3	6	7043.60	70.50
			5	7109.60	80.50
			4	7769.00	93.50
227	226FS	0.4	6	7043.60	66.40
			5	7109.60	76.40
428	184FS	0.3	70	199,033.33	77.70
			60	253,930.00	90.70
429	184FS	0.3	90	52,700.00	80.00
			70	64,400.00	93.00
430	184FS	0.3	70	16,200.00	92.20
431	184FS	0.3	130	248,570.27	67.00
			70	300,000.00	77.00
			60	372,895.56	90.00
432	184FS	0.2	130	13,809.45	73.70
			70	16,666.67	83.70
			60	20,716.42	96.70
433	184FS	0.2	130	19,333.24	66.40
			70	23,333.33	76.40
			60	29,002.98	89.40
434	184FS	0.3	130	27,618.91	68.00
			70	33,333.33	78.00
			60	41,432.84	91.00
435	184FS	0.3	130	33,142.70	70.00
			70	40,000.00	80.00
			60	49,719.40	93.00
436	184FS	0.3	130	8285.67	67.90
			70	10,000.00	77.90
			60	12,429.85	90.90
437	184FS	0.1	130	23,476.80	67.50
			70	28,333.33	77.50
			60	35,217.91	90.50
438	4FS	0.1	70	9200.00	68.90
			43	10,000.00	78.90
			35	12,429.85	91.90
439	441FS-10	0.2	1	7371.34	72.90
			1	10,000.00	82.90
			1	12,429.85	95.90
440	184FS	0.2	130	248,570.67	68.60
			70	300,000.00	78.60
			60	372,895.56	91.60
441	184FS	0.2	130	198,856.22	72.00
			70	240,000.00	82.00
			60	298,316.45	95.00
442	184FS	0.3	130	69,047.29	70.50
			70	83,333.33	80.50
			60	103,582.10	93.50
443	184FS	0.6	130	497,140.55	73.30
			70	600,000.00	83.30
			60	745,791.13	96.30
444	184FS	0.3	130	27,618.91	68.50
			70	33,333.33	78.50
			60	41,432.84	91.50
445	1FS	0.1	20	41,666.67	95.30
446	1FS	0.4	110	25,000.00	95.90
447	3FS, 48FS, 159FS, 163FS, 188FS, 190FS, 215FS, 217FS, 243FS, 244FS, 270FS, 273FS, 299FS, 300FS, 326FS, 351FS, 376FS,	-	-	-	-

			4	7769.00	89.40	401FS, 404FS, 409FS, 411FS, 417FS, 419FS, 420FS, 421FS, 422FS, 423FS, 424FS, 425FS, 426FS, 427FS, 428FS, 429FS, 430FS, 431FS, 432FS, 433FS, 434FS, 435FS, 436FS, 437FS, 438FS, 439FS, 440FS, 442FS, 443FS, 444FS, 445FS, 446FS
228	227FS	0.2	6	7043.60	69.30	
			5	7109.60	79.30	
			4	7769.00	92.30	
229	228FS	0.2	6	7043.60	68.60	
			5	7109.60	78.60	
			4	7769.00	91.60	
230	229FS	0.3	6	7043.60	68.50	
			5	7109.60	78.50	
			4	7769.00	91.50	
231	230FS	0.2	6	7043.60	73.10	
			5	7109.60	83.10	
			4	7769.00	96.10	
232	231FS	0.1	6	7043.60	71.70	
			5	7109.60	81.70	
			4	7769.00	94.70	

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