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Time-Cost-Quality Trade-off Software by using Simplified Genetic Algorithm for Typical-repetitive Construction Projects

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***Abstract*—**Time-Cost Optimization "TCO" is one of the greatest challenges in construction project planning and control, since the optimization of either time or cost, would usually be at the expense of the other. Since there is a hidden trade-off relationship between project and cost, it might be difficult to predict whether the total cost would increase or decrease as a result of the schedule compression. Recently third dimension in trade-off analysis is taken into consideration that is quality of the projects. Few of the existing algorithms are applied in a case of construction project with three-dimensional trade-off analysis, Time-Cost-Quality relationships. The objective of this paper is to presents the development of a practical software system; that named Automatic Multi-objective Typical Construction Resource Optimization System "AMTCROS". This system incorporates the basic concepts of Line Of Balance "LOB" and Critical Path Method "CPM" in a multi-objective Genetic Algorithms "GAs" model. The main objective of this system is to provide a practical support for typical construction planners who need to optimize resource utilization in order to minimize project cost and duration while maximizing its quality simultaneously. The application of these research developments in planning the typical construction projects holds a strong promise to: 1) Increase the efficiency of resource use in typical construction projects; 2) Reduce construction duration period; 3) Minimize construction cost (direct cost plus indirect cost); and 4) Improve the quality of newly construction projects. A general description of the proposed software for the Time-Cost-Quality Trade-Off "TCQTO" is presented. The main inputs and outputs of the proposed software are outlined. The main subroutines and the inference engine of this software are detailed. The complexity analysis of the software is discussed. In addition, the verification, and complexity of the proposed software are proved and tested using a real case study.

***Keywords*—**Project Management, Typical (repetitive) Large-scale Projects, Line Of Balance, Multi-Objective Optimization, Genetic Algorithms, and Time-Cost-Quality Trade-Offs.

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I. Introduction

IT was declared the three classic design and construction objectives are quality, cost, and time for project construction; 1) Quality: may mean beauty, function, performance, sometimes quality is more important even though it costs more and take more time; 2) Cost: may mean initial or long-term prices, most clients have tight budgets that actually define the scope of their projects; and 3) Time: may mean as soon as possible or by a specific data, some clients have inflexible dead lines [1]. It was mentioned that the Project Quality Management includes the processes to ensure that the project will satisfy the needs for which it was undertaken. The following major project quality management processes: 1) Quality Planning: identifying which quality standards arc relevant to the project and determining how to satisfy them; 2) Quality Assurance: Evaluating overall project performances on a regular basis to provide confidence that the project will satisfy the relevant qualify standards; and 3) Quality Control: monitoring specific project results to determine if they comply with relevant quality standards and identifying ways to eliminate causes of unsatisfactory performance. These processes interact with each other and with the processes in the other knowledge areas as well [2].

It was discussed this concept through several dimensions, quality is not relevant what we think quality is, the quality that matters is what client think and also is willing to pay for it. Standard; quality are created over long period by habits, culture and customs which differ greatly from place to place and from a group of individuals to another. Therefore, it must be understood that Quality is not a term that can be defined simply. Rather, it is a composite term, expressed in terms of attributes [3], [4]. It was described a method capable of obtaining managers' consensus opinion on factors to improve quality on their projects [5]. Measurement is the trigger for improvement [6]. It was stated, "Problems surrounding perception, interpretation and assessment of quality resulted from the shortage of measurement" [7]. It was concluded 16 factors for quality improvement in the Egyptian construction industry, and emphasized the importance of quality measurement [8]. It was developed and applied a model capable of measuring the quality of construction projects. This model, though applicable but it is not based on calculating the actual cost of poor quality [9]. It was developed and applied technique to measure the quality of foundation pilling construction [10].

II. Review

A. Time-Cost Trade-off:

It was developed a GA model for construction time-cost trade-off analysis. The developed model calculates values of project cost and duration for each individual in the population, which can be represented by a point on the cost and duration plot. Then the distance of each point in each generation from each segment of the convex hull of that generation is calculated. The difference between the maximum and minimum distance of each point is its fitness value, and affects it probability of selection [11]. It was developed a model that utilizes discrete event simulation, GAs, and object oriented programming to optimize project cost and duration of earthmoving operations simultaneously [12]. It was developed a multi-objective GA for solving the time-cost trade-off problem [13]. The GA utilized a method called the **A**daptive **W**eight **A**pproach "**AWA**", which uses a fitness function those factors in the values of time and cost of each chromosome using weights that adjust at every generation. The GA uses a chromosome similar to the one used in the [11] formulation. The authors later suggested a modification to improve AWA, to avoid potential errors in this method in [14]. Also he presented the development of the stochastic approach to multi-objective optimization in construction projects using fuzzy sets theory [15]. It was presented a genetic algorithm-based multi-objective optimization model for the scheduling of linear construction projects. The model allows construction planners to generate and evaluate optimal/ near-optimal construction scheduling plans that minimize both project time and cost [16]. It was proposed a mathematical model for time-cost trade-off based on the integration between the principles of LOB and CPM. The output of this model is to determine the crashed duration for each activity which corresponding to minimum project total cost [17].

B. Time-Cost-Quality Trade-off:

It was proposed a new method to study the trade-off among time, cost and quality using three interrelated linear programming models. Their approach is based on the linear relationship among the project cost, the quality measure and the project completion time [18]. It was applied the time-cost-quality trade-off to an actual cement factory construction project [19]. It was designed modified GA model, which transform the traditional two-dimensional time-cost trade-off analysis to an advanced three-dimensional time-cost-quality trade-off analysis. The model is developed as a multi-objective genetic algorithm to provide the capability of quantifying and considering quality in construction optimization [20]. It was developed a solution procedure to study the tradeoffs among time, cost and quality in the management of a project. Three inter-related integer programming models are developed [21]. It was proposed a meta-heuristic solution procedure which called electromagnetic scatter search to solve the discrete time, cost and quality trade-off problem. The validity of the proposed solution procedure is demonstrated, and its applicability is tested on a randomly generated large and complex problem having 19900 activities [22]. It was proposed a new meta-heuristic multi-colony ant algorithm is developed for the optimization of three objectives time-cost-quality as a trade-off problem. An example is analyzed to illustrate the capabilities of the present method in generating optimal/near optimal solutions [23]. It was proposed a new Multi Objective Particle Swarm Optimization for a discrete time, cost and quality trade-off problem [24]. It was purposed multi-objective for finding the Pareto optimal front of time, cost and quality of a project, whose activities belong to a start to finish activity relationship network (CPM) and they can be done in different possible modes which are non-continuous or discrete, and each mode has a different time, cost, and quality [25].

III. Considered Assumptions of Proposed Software

The mathematical formulation of the model is based on the following assumptions: 1) No idle time is allowed for employed crews, thus once a crew starts working on an activity at the first stage it will continue working with the same production rate until finishing the work on the last stage; 2) A constant duration is set for the same activity at all stages to maintain a constant production rate. If an activity duration needs to be changed to meet a particular feasible project duration, then an equal change must be made to the activity duration at all stages; 3) The learning phenomenon, where the duration of an activity is reduced as repetition increases, is neglected; and 4) The work on each activity is conducted one unit at a time.

IV. AMTCROS Software

Automatic **M**ulti-objective **T**ypical **C**onstruction **R**esource **O**ptimization **S**ystem "**AMTCROS**" software is designed by java programming code system (e.g., eclipse software) to provide a number of new and unique capabilities, including: 1) Ranking the obtained optimal plans according to a set of planner specified weights that represent the relative importance of time, cost, and quality in the analyzed project; 2) Visualizing and viewing the generated optimal trade-off among construction duration, cost, and quality according to planner ranking relative weights to facilitate the selection of an optimal plan that considers the specific project needs; and 3) Providing seamless integration with available project management calculations to benefit from their practical project scheduling and control features. In order to provide the aforementioned capabilities of **AMTCROS** software, the system is implemented as shown in Figure 1 and developed in four main modules, as shown in Figure 2: 1) A relational database module to facilitate the storage and retrieval of construction scheduling, resource utilization, and optimal trade-off data; 2) A logical module to provide a seamless integration of the project relational database with modifying module and multi-objective optimization model and responsible for all calculations runs; 3) A modifying module to change the duration and relations of each activity in the project at one stage to modified duration and relations of each activity in the project at all stages <u>L</u>ine <u>O</u>f <u>B</u>alance "**LOB**" as a one stage Modified <u>C</u>ritical <u>P</u>ath <u>M</u>ethod "**CPM**"; and 4) A user interface module to facilitate the input of project data and the visualization of the three-dimensional time-cost-quality trade-off generated by the system.

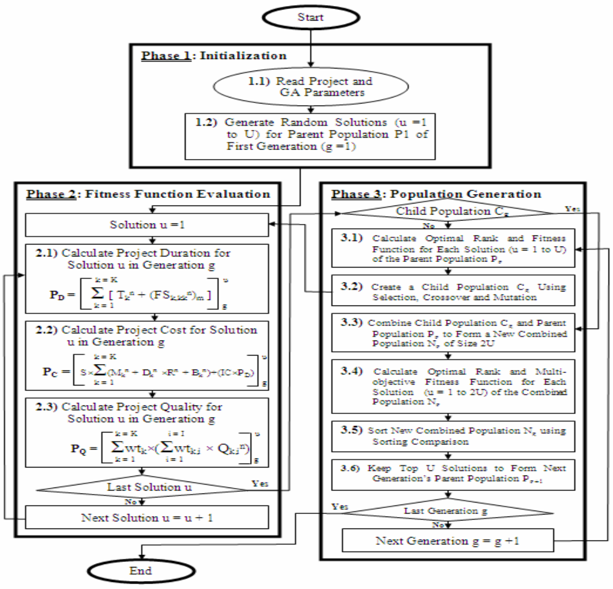

Fig. 1 Model Implementation

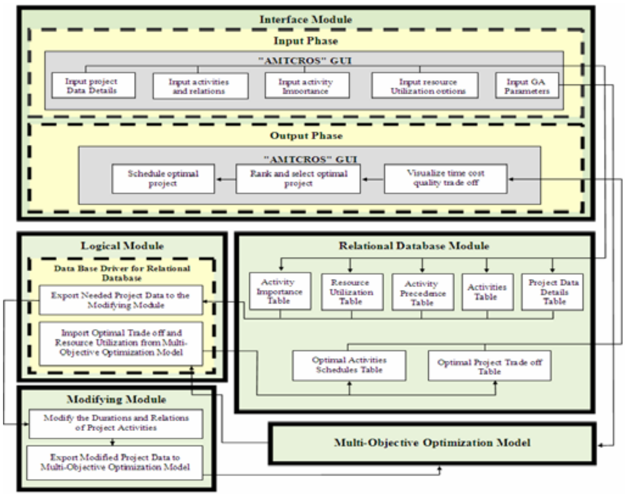

Fig. 2 The Main Modules of "AMTCROS" System

V. Relational Database Module

The main purpose of this module is to develop a relational database that is capable of storing the necessary input data (e.g., project data details, project activities and available resource utilization options) and the produced output data (e.g., generated optimal trade-off among construction quality, cost, and duration). This module is composed of nine main tables that are designed to store the following construction planning information: 1) Project data details table; 2) Project holidays data table; 3) Project exception data table; 4) Project activities table; 5) Successors relationships among activities table; 6) Available resource utilization options for each activity table; 7) Quality importance weight for each activity table; 8) Optimal activities schedules and optimal resource utilization option for each activity table; and 9) Optimal project time-cost-quality trade-off. A schematic representation of these database tables and the relationships among them is shown using an entity relationship diagram (see Figure 3). The project data details table in this module is designed to store the IDs and descriptions of all repetitive construction projects, number of project stages, project start date, and project weekends. It is linked to the project activities table, project holidays data table, and project exception data table using a one to many relationships. The project holidays data table, which include project ID, holiday ID, holiday start date, holiday end date and repeated holidays. It is linked to the project data details table using a many to one relationship. The project exceptions data table, which include project ID, exception ID, exception start date, and exception end date, that is linked to the project data details table using a many to one relationship. The project activities table in this module is designed to store the descriptions and IDs of all project activities, which is linked to the activity importance weight table using a one to one relationship. The project activities table is also linked using a one to many relationships to: 1) The successors activity table that stores the successors, lag time of each activity and stage buffers between sequential Activities; and 2) The resource utilization table that stores the feasible resource utilization options for each activity (see Figure 3). The activities table is also linked using a many to many relationships to the optimal activity schedules table that is designed to store the identified optimal schedule for each activity, including its: 1) Optimal resource utilization option; 2) Optimal duration, cost and quality; and 3) Optimal first stage start time and last stage finish time. The optimal activity schedules table is also linked to the optimal project trade-off table which stores the identified set of optimal trade-off among the project duration, cost, and quality as shown in Figure 3. The main purpose of the relationships linking the tables in the relational database module is to ensure the integrity of the data stored in the database during the input and output phases. For example, the relationship linking the activities table to the resource utilization table is specified to be a one to many relationships to ensure that each entered resource utilization option is assigned to unique activity in the project. On the other hand the data stored in each of the aforementioned project data details, activities data, activity importance weight, the resource utilization and activity successors tables, need to be populated by manually entering using the user interface input module in "**AMTCROS**" software (see Figure 2), while the two remaining tables of optimal activity schedules and project trade-off are populated by the multi-objective optimization model after performing its genetic algorithm computations using the user interface output module in "**AMTCROS**" software**,** as shown in Figure 2. The present relational database module is developed using the Java programming code which called Derby database management system to facilitate its integration with the remaining modules of "**AMTCROS**" software using logical module modifying module and which is described in more details in the following sections. Figure 3 shows all relational database tables Designs with all available links between these tables, that are specified to be a one to one relationship, or that are specified to be a one to many relationships, or that are specified to be a many to many relationships, as shown in the following table.

VI. Logical Module

Logical can be defined as a class of programming code system especially java coding and its applications that are designed to allow different calculation runs on a computer to communicate and exchange data from available modules. The present logical module is developed in "**AMTCROS**" software to enable the integration of the relational database module with the user interface module with modifying module and the multi-objective optimization model. To accomplish this, the logical module is designed by java programming code (e.g., eclipse software) driver, as shown in Figure 2: 1) The Java programming code driver; and 2) The Derby data base driver. First, the java programming code driver is utilized to perform two main functions: 1) Export scheduling data from the project, activity, successors, and resource utilization tables in the relational database module to modifying module; and 2) Import the generated results from the multi-objective optimization model to the optimal activity schedules and optimal project trade-off tables in the relational database module. Second, the derby driver is used in "**AMTCROS**" software to perform two main functions: 1) Export the existing project scheduling data form the "**AMTCROS**" software input interface module to the activities and successors relationship table in the relational database module; 2) Import the selected optimal scheduled data that obtained by multi-objective optimization model from the relational database module to "**AMTCROS**" software output interface module to facilitate its visualization and storage using the eclipse software. The main data transferred using the two drivers in the present logical module are the data in "**AMTCROS**" software using a newly developed user interface modules.

VII. Modifying Module

Modifying module can be defined as a class of programming code system especially java coding and its applications (e.g., eclipse software), that are designed to modify the activities durations and relations between sequential activities from one stage to all stages (Modified **C**ritical **P**ath **M**ethod "**CPM**"). The present modifying module is developed in "**AMTCROS**" software to enable the integration of the logical module with the multi-objective optimization model. To accomplish this, the modifying module is designed to utilize the java programming code driver, as shown in Figure 2: 1) Modify the scheduled data that exported by logical module from the project, activity, successors, and resource utilization tables in the relational database module to modifying module; and 2) Import the modified scheduling data of project, activity, successors, and resource utilization tables to multi-objective optimization model. The main data transferred using the java programming code driver in the present modifying module are scheduled data in a relational data base module in "**AMTCROS**" software using a newly developed user interface module.

VIII. User Interface module

The present user interface module is implemented in "**AMTCROS**" software to facilitate the input of all the necessary construction planning data and the output of the generated optimal schedules. The module is designed to implement the necessary interface functions in two main phases: 1) An input phase that facilitates the input of project data details, project activities, activities relations, activities importance weights, available resource utilization options, and genetic algorithm parameters; and 2) An output phase that allows the user to rank and visualize the optimal project scheduling solutions and optimal activity resource utilization options that obtained by the multi-objective optimization model. In each of these two phases, the module is designed to enable an effective and graphical interface with construction planners using newly developed **G**raphical **U**ser **I**nterface "**GUI**" forms in "**AMTCROS**" software, as shown in Figure 2. The **GUI** forms are used to benefit from the practical capabilities of the "**AMTCROS**" software in order to facilitate: 1) The creation of an initial project schedule in the pre-optimization phase in "**AMTCROS**" software; and 2) The presentation, analysis, and control of the generated optimal schedule in the post optimization phase.

On the other hand, the newly developed "**AMTCROS**" software **GUI** forms are implemented using java programming code net to benefit from its advanced programming capabilities in order to facilitate the integration of the different modules of "**AMTCROS**" software, the multi-objective optimization model, and java programming code with all related applications including derby data base driver (relational data base module), Modify the imported data that came from relational data base module by logical module (modifying module), and all runs with scheduling calculations (logical module).

The following two sections describe the flow of data between the construction planner and the different components of "**AMTCROS**" software during the input and output phases, which are executed after the start of the program as declared in "**AMTCROS**" software welcome form with all important relational information (e.g., developing, supervising, and designing), start software button, and exit software button, as viewed in Figure 4.

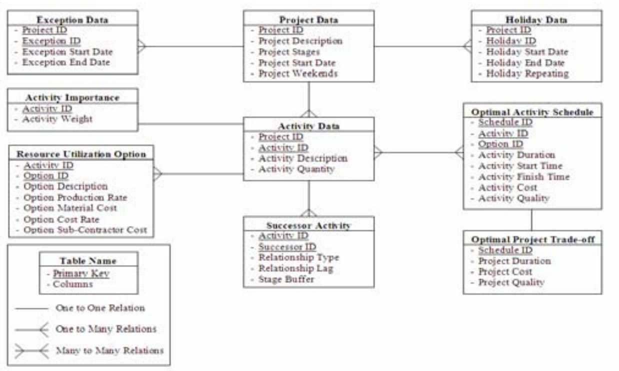

Fig. 3 Relational Database Design

Fig. 4 "AMTCROS" Welcome Form

IX. Input Phase

The input phase is designed to facilitate and simplify the input of the necessary construction planning and optimization in "**AMTCROS**" software. To accomplish this, a set of interactive **GUI** forms are developed to guide the planner in entering the necessary data in four main steps that are designed to: 1) Allow for adding, editing and deleting of the available projects by using edit existing projects button, add a new projects button, delete existing projects button, and cancel form button, as shown in Figure 5; 2) Allow for manual inserting or editing the data details of the project, which includes project ID, project name, project location, company name, manager name, number of project stages, project start date, project weekends, project activities button, project activities relationships button, project holidays button, project exceptions buttons, genetic algorithm parameters button, optimize project solutions button, save form button, and cancel form button, as shown in Figure 6; 3) Allow for adding, editing and deleting of the available project activities by using edit existing project activities button, add a new project activities button, delete existing project activities button, and cancel form button, as shown in Figure 7; 4) Allow for manual inserting or editing the data details of the project activity, which includes activity ID, activity description, activity weight, the quantity of activity, activity options IDs, activity options descriptions, edit existing activity options button, add a new activity options button, delete existing activity options button, save form button, and cancel form button, as shown in Figure 8; 5) Allow for manual sequence inserting or editing the details of activity resource utilization options, which includes activity option ID, activity option description, activity option production rate in units/day, activity option material cost in EGP/stage, activity option cost rate in EGP/day, activity option subcontractor cost in EGP/stage, first weight of quality indicator at each activity, second weight of quality indicator at each activity, third weight of quality indicator at each activity (the three weights values varied between 0.00 : 1.00 and the summation of three weights values must be equal one), first performance of quality indicator at each activity option in (%), second performance of quality indicator at each activity option in (%), third performance of quality indicator at each activity option in (%), save form button, and cancel form button, as shown in Figure 9; 6) Allow for adding, editing and deleting of the available project activities relationships by using edit existing project activities relationships button, add a new project activities relationships button, delete existing project activities relationships button, and cancel form button, as shown in Figure 10; 7) Allow for manual sequence inserting or editing the data details of the two activities relationship, which includes activity ID, successor activity ID, the relationship type (Finish to Start, Start to Start, Finish to Finish, Start to Finish), the relationship value (Lag Value), stage buffer, save form button, and cancel form button, as shown in Figure 11; 8) Allow for adding, editing and deleting of the available project holidays by using edit existing project holidays button, add a new project holidays button, delete existing project holidays button, and cancel form button, as shown in Figure 12; 9) Allow for manual sequence inserting or editing the data details of the project holidays, which includes holiday start date, holiday end date, repeat holiday every year or not, save form button, and cancel form button, as shown in Figure 13; 10) Allow for adding, editing and deleting of the available project exceptions by using edit existing project exceptions button, add a new project exceptions button, delete existing project exceptions button, and cancel form button, as shown in Figure 14; 11) Allow for manual sequence inserting or editing the data details of the project exceptions, which includes exception start date, exception end date, save form button, and cancel form button, as shown in Figure 15; and 12) Specify the genetic algorithm parameters that will be mentioned in all details at the next statement used for starting software for getting the optimized project solutions, save form button, and cancel form button, as shown in Figure 16. The final step of the input phase of the present user interface module is designed to facilitate the input of the genetic algorithm parameters needed to initiate the multi-objective optimization model. The main parameters that are captured in this step include: 1) The genetic algorithm population size; 2) The number of genetic algorithm generations needed; 3) The type of crossover implemented by the genetic algorithm (simple, double, multiple); 4) Crossover probability its value varied between (0.00 : 1.00); 5) The mutation probability its value varied between (0.00 : 1.00); and 6) The random number its value varied between (0.00 : 1.00) that used to create the first population of solutions. These input parameters are determined as a function of the number of activities in the project, and are transferred directly to the multi-objective optimization model. The multi-objective optimization process is then invoked by clicking the solutions button in the project details form, as shown in Figure 6.

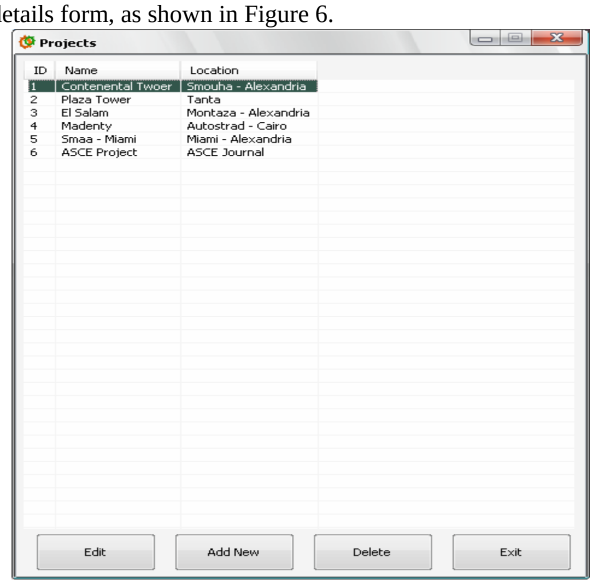

Fig. 5 Projects Form

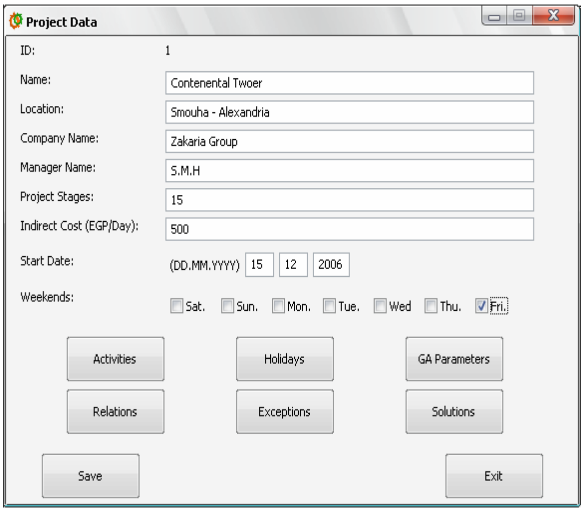

Fig. 6 Project Details Form

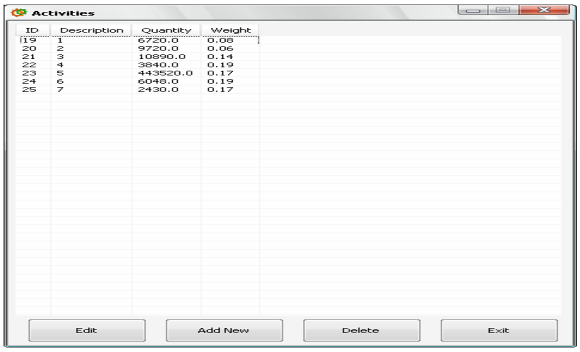

Fig. 7 Project Activities Form

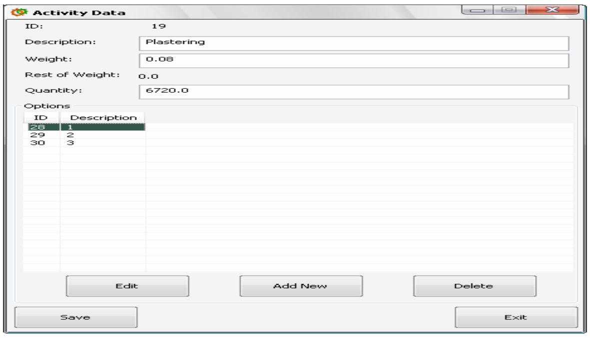

Fig. 8 Project Activities Details Form

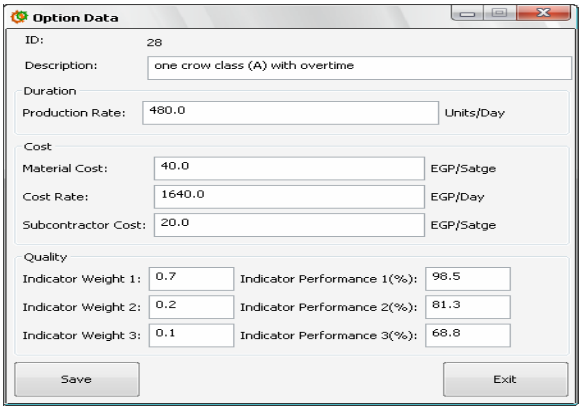

Fig. 9 Project Activities Resource Utilization Options Form

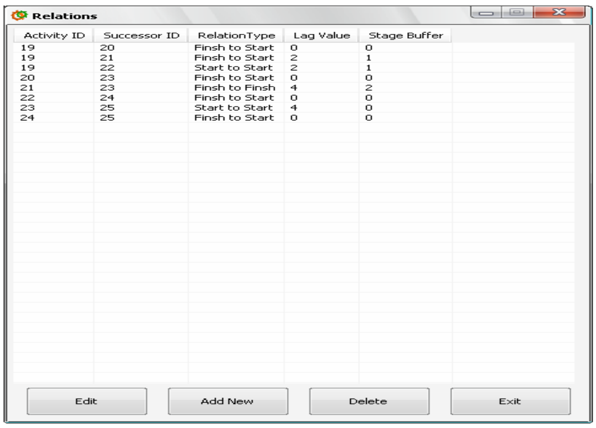

Fig. 10 Project Activities Relationships Form

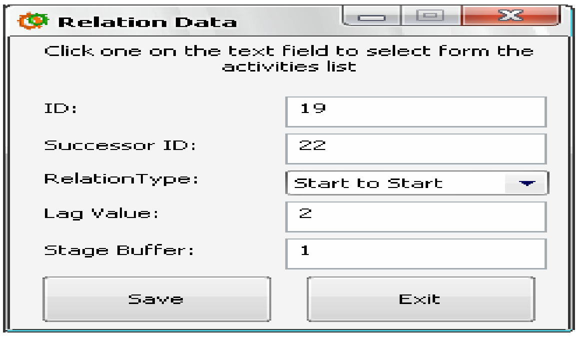

Fig. 11 Project Activities Relationships Details Form

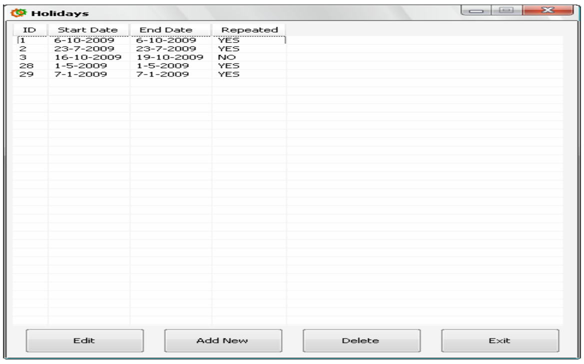

Fig. 12 Project Holidays Form

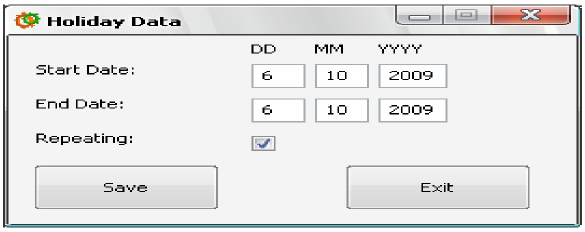

Fig. 13 Project Holidays Details Form

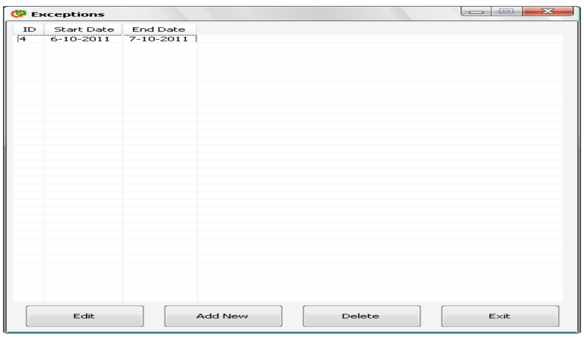

Fig. 14 Project Exceptions Form

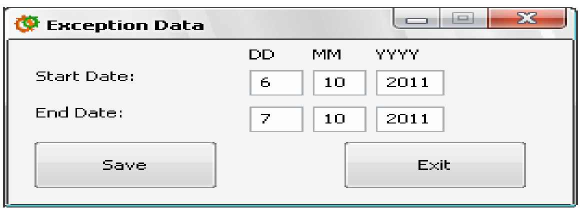

Fig. 15 Project Exceptions Details Form

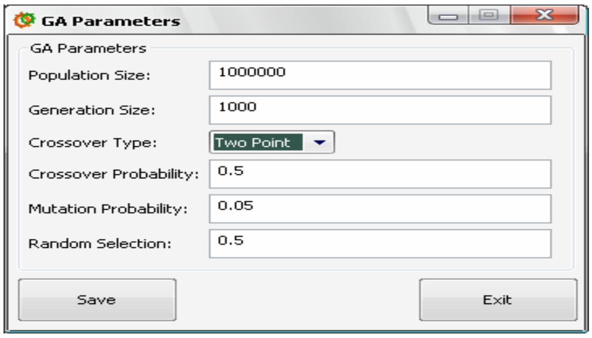

Fig. 16 Project Genetic Algorithm Parameters Form

After the project is optimized by relative project time, cost, and quality importance weights form the obtained results are then ranked and visualized in the output phase of the present module.

X. Output Phase

The output phase of the present user interface module is designed to facilitate the visualization and viewing of the generated optimal trade-off among project time, cost, and quality and the selection of an optimal schedule for the planned project. To accomplish this, the output phase is executed in five main steps that are designed to: 1) Rank the generated optimal project solutions using a set of weights that specify the relative importance of time, cost, and quality to the construction planner in the analyzed project, and allow the construction planner to scroll through the ranked optimal project solutions as shown in Figure 17; 2) Display the obtained project time-cost-quality trade-off in a three-dimensional scatter plot and allow the construction planner to scroll through the generated optimal solutions, as shown in Figure 18; 3) Scheduling the selected optimal project solution by using "**AMTCROS**" software, such as project duration in days, project start date, project end date, project cost in EGP, and project quality in %. After that obtain the scheduling all activities of selected optimal project solution by using "**AMTCROS**" software, such as activity ID, optimal used option number for each activity in selected optimal project solution to give corresponding activity duration in days per project, activity start date, activity end date, activity cost in EGP per project, and activity quality in % per project, see Table 4; 4) Scheduling the activities of selected optimal project solution by using bar chart view as shown in Figure 19; and 5) Print all data details of scheduled activities in optimized selected project solution. The project solution ranks are calculated in the second step of this phase by: 1) Identifying the solutions that provide the maximum value of each of the three optimization objective; 2) Normalizing all the obtained project solutions using the identified maximum values to eliminate the influence of the magnitude of each objective in the overall ranking process; and 3) Aggregating the normalized values of the three objectives for each solution in the trade-off in order to sort and rank the project solutions.

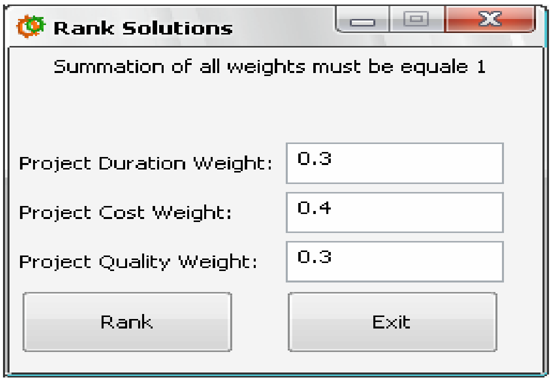

Fig. 17 Ranked Project Solutions Form

XI. Case Study

This section presents the results of a practical optimization software **AMTCROS**. The main objective of these results of present system is to provide fixed small solutions for typical construction projects that we need to optimize resource utilization in order to simultaneously minimize project cost and duration while maximizing its quality. To accomplish this, **AMTCROS** software run to provide a number of new and unique capabilities, including a real case study with area approximately one thousand meter square at Semoha in Alexandria that is analyzed to illustrate the use of **AMTCROS** software and demonstrate its capabilities in generating optimal time-cost-quality trade-off for typical construction projects. The analyzed case study project is composed of fifteen typical floors and twenty three repetitive construction activities for each floor. The indirect project cost equal five hundred EGP per working day. The project activities details were declared at table 1. The enumeration of all possible combinations of these available resource utilization options at the activity level can lead to a total of approximately 4×10^{25} feasible construction resource utilization plans at the project. First in the input phase, the construction planner can enter the main data of the construction project data details, activities data, activities relations, activities resource utilization options, and genetic algorithm parameters in the analyzed project using the practical features of the **AMTCROS** software **GUI** forms (see Table 1), also the activities of this initial schedule can be viewed and edited. This scheduling data is stored in the relational database module of **AMTCROS** software. This **GUI** form also allows the planner to enter the relative importance of each activity to the overall quality of the project. Allow for adding, editing and deleting of the available project holidays and project exceptions. The final step of the input phase requires the planner to enter the genetic algorithm parameters and to start the execution of the optimization procedure. Second in the output phase to further facilitate the evaluation and selection from these optimal solutions, **AMTCROS** software can be used to rank the obtained solutions based on a set of planner-determined weights that signify the relative importance of each objective to the evaluated project solutions. **AMTCROS** software facilitates the graphical evaluation of the generated optimal time-cost-quality trade-off for this project using the three-dimensional scatter plot shown in Figure 18. The final step of the output phase gives to the planner complete scheduling details of optimal selected project solution, as shown in Table 4 with view of all activities bar chart, as shown in Figure 19. On the other hand these details can be printed. A number of what-if scenarios were tested for the analyzed construction project, as mentioned in Table 2. Table 3 shows the project activities details of optimal what-if Scenarios. These scenarios evaluated important different sets of importance weights that were selected to find optimal project solutions that lead to find: 1) A trade-off among the three project objectives with a less emphasis on project duration; 2) A trade-off among the three project objectives with a less emphasis on project cost; 3) A trade-off among the three project objectives with a greater emphasis on project quality; 4) A trade-off among the three project objectives that gives a less emphasis on project duration and a less emphasis on project cost simultaneously; 5) A trade-off among the three project objectives that gives a less emphasis on project duration and a greater emphasis on project quality simultaneously; 6) A trade-off among the three project objectives that gives a less emphasis on project cost and a greater emphasis on project quality simultaneously; 7) A simultaneously trade-off among project time, cost, and quality, as shown in Table 4. Figure 18, declare the view and management of the case study schedule scenarios using time-cost-quality trade-off in the advance project scheduling and control capabilities of **AMTCROS** software **GUI**. Figure 19, shows **AMTCROS** bar chart view of project activities with balanced trade-off among project time, cost, and quality.

TABLE 1
Project Activities Details of Real Case Study

Activity ID	NO. of Options	Successor	Relation	Stage Buffer
01	16	02	FS = 0	SB = 0
02	08	03	SS = 2	SB = 1
		04	FS = 0	SB = 2
		05	FS = 0	SB = 2
		06	SS = 3	SB = 1
03	16	08	FS = 0	SB = 1
		12	FS = 5	SB = 2
04	08	07	FS = 0	SB = 1
		08	FS = 0	SB = 1
05	08	07	FS = 0	SB = 1
		08	FS = 0	SB = 1
06	08	08	FS = 0	SB = 1
07	08	13	FS = 1	SB = 1
		14	FS = 1	SB = 1
08	08	09	FS = 1	SB = 1
		14	FS = 1	SB = 1
09	08	10	FS = 0	SB = 1
10	08	11	FS = 2	SB = 1
		12	FS = 1	SB = 1
		13	FS = 0	SB = 1
		15	FS = 2	SB = 1
11	16	17	FS = 0	SB = 1
12	16	19	FS = 0	SB = 0

CONT. TABLE 1
PROJECT ACTIVITIES DETAILS OF REAL CASE STUDY

Activity ID	NO. of Options	Successor	Relation	Stage Buffer
13	16	16	FF = 4	SB = 0
		23	FS = 2	SB = 1
14	16	22	FS = 2	SB = 1
		23	FS = 2	SB = 1
15	08	17	FS = 0	SB = 1
16	16	17	FS = 0	SB = 1
17	08	18	FS = 1	SB = 1
18	16	19	SS = 0	SB = 0
		22	FS = 0	SB = 1
19	12	20	FS = 1	SB = 1
		21	FS = 0	SB =1
20	16	--	--	--
21	16	--	--	--
22	16	--	--	--
23	16	--	--	--

TABLE II
OPTIMAL WHAT-IF SCENARIOS

Scenario	Ranking Scenarios Focus			Ranked Optimal Solutions				
	Duration Weight	Cost Weight	Quality Weight	Project Duration	Project Dates Start	Project Dates End	Project Cost	Project Quality
01	1.0	0.0	0.0	197 Days	01/08/2008	29/03/2009	07,053,843 EGP	91 %
02	0.0	1.0	0.0	322 Days	01/08/2008	25/08/2009	06,350,975 EGP	80 %
03	0.0	0.0	1.0	209 Days	01/08/2008	12/04/2009	12,615,438 EGP	96 %
04	0.5	0.5	0.0	198 Days	01/08/2008	30/03/2009	06,913,095 EGP	86 %
05	0.5	0.0	0.5	202 Days	01/08/2008	04/04/2009	20,246,980 EGP	96 %
06	0.0	0.5	0.5	244 Days	01/08/2008	25/05/2009	07,540,445 EGP	94 %
07	0.4	0.4	0.2	200 Days	01/08/2008	01/04/2009	07,241,350 EGP	93 %
08	0.4	0.2	0.4	202 Days	01/08/2008	04/04/2009	08,975,991 EGP	95 %
09	0.2	0.4	0.4	209 Days	01/08/2008	12/04/2009	08,450,298 EGP	95 %
10	0.6	0.2	0.2	198 Days	01/08/2008	30/03/2009	08,048,610 EGP	94 %
11	0.2	0.6	0.2	202 Days	01/08/2008	04/04/2009	07,171,295 EGP	93 %
12	0.2	0.2	0.6	209 Days	01/08/2008	12/04/2009	08,450,298 EGP	95 %
13	0.4	0.3	0.3	199 Days	01/08/2008	31/03/2009	08,013,650 EGP	94 %
14	0.3	0.4	0.3	200 Days	01/08/2008	01/04/2009	07,795,135 EGP	93 %
15	0.3	0.3	0.4	205 Days	01/08/2008	07/04/2009	08,651,210 EGP	95 %

TABLE III
DETAILS OF OPTIMAL WHAT-IF SCENARIOS

Scenario	Ranking Scenarios Focus			Activity Option of Optimal Ranked Solutions										
	Duration Weight	Cost Weight	Quality Weight	01	02	03	04	05	06	07	08	09	10	11
01	1.0	0.0	0.0	14	07	06	05	07	05	05	07	05	05	08
02	0.0	1.0	0.0	04	04	08	02	02	04	04	04	06	08	16
03	0.0	0.0	1.0	13	07	03	07	07	05	05	05	05	05	03
04	0.5	0.5	0.0	12	07	06	06	02	08	04	07	05	05	08
05	0.5	0.0	0.5	13	07	03	07	07	05	05	07	05	05	07
06	0.0	0.5	0.5	13	08	03	07	07	05	05	07	05	05	15
07	0.4	0.4	0.2	13	07	03	07	07	05	05	05	05	05	08
08	0.4	0.2	0.4	13	07	02	07	07	05	05	05	05	05	04
09	0.2	0.4	0.4	13	07	03	07	07	05	05	05	05	05	03
10	0.6	0.2	0.2	13	07	02	07	07	05	05	05	05	05	08
11	0.2	0.6	0.2	13	07	03	07	07	05	05	05	05	05	07
12	0.2	0.2	0.6	13	07	03	07	07	05	05	05	05	05	03
13	0.4	0.3	0.3	13	07	02	07	05	05	07	05	05	05	07
14	0.3	0.4	0.3	14	07	03	07	07	06	05	07	05	05	07
15	0.3	0.3	0.4	13	07	02	07	07	05	05	05	05	05	03

CONT. TABLE III
DETAILS OF OPTIMAL WHAT-IF SCENARIOS

Scenario	Ranking Scenarios Focus			Activity Option of Optimal Ranked Solutions											
	Duration Weight	Cost Weight	Quality Weight	12	13	14	15	16	17	18	19	20	21	22	23
01	1.0	0.0	0.0	15	16	16	08	14	05	15	03	11	15	13	06
02	0.0	1.0	0.0	08	16	08	04	08	05	08	06	16	08	08	08
03	0.0	0.0	1.0	12	11	11	05	05	05	11	10	11	11	15	13
04	0.5	0.5	0.0	08	08	08	04	06	05	15	04	16	08	13	08
05	0.5	0.0	0.5	12	15	16	05	14	05	15	03	11	11	15	13
06	0.0	0.5	0.5	12	15	16	05	15	05	15	10	11	11	15	13
07	0.4	0.4	0.2	15	15	16	05	14	05	15	03	11	11	13	13
08	0.4	0.2	0.4	12	15	11	05	14	05	15	03	11	11	13	13
09	0.2	0.4	0.4	03	15	15	05	14	05	11	10	11	11	15	13
10	0.6	0.2	0.2	03	15	15	05	14	05	15	03	11	11	13	13
11	0.2	0.6	0.2	07	15	16	07	14	05	15	03	11	11	15	13
12	0.2	0.2	0.6	03	15	15	05	14	05	11	10	11	11	15	13
13	0.4	0.3	0.3	03	15	16	05	14	05	15	03	11	11	13	13
14	0.3	0.4	0.3	03	16	16	07	14	05	15	03	15	11	13	06
15	0.3	0.3	0.4	03	15	15	05	14	05	11	10	09	11	15	13

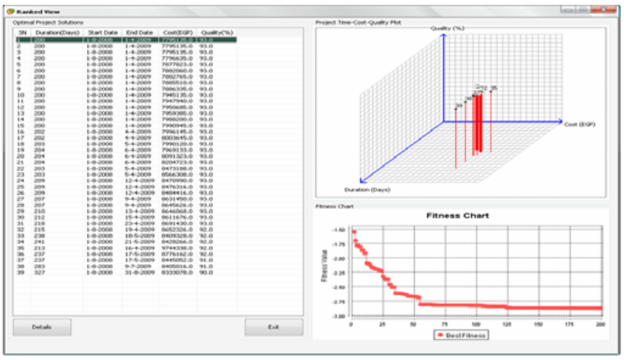

Fig. 18 AMTCROS Output of Optimal Time-Cost-Quality Trade-Off

TABLE IV
PROJECT ACTIVITIES DETAILS OF OPTIMAL TIME-COST-QUALITY TRADE OFF

Act ID	Option Number	Activity Duration	Activity Dates Start	Activity Dates End	Activity Cost	Activity Quality
01	14	18 Days	01/08/08	20/08/08	024,880 EGP	92.6 %
02	07	41 Days	02/08/08	17/09/08	025,710 EGP	95.9 %
03	03	18 Days	28/08/08	17/09/08	006,920 EGP	95.2 %
04	07	50 Days	09/08/08	08/10/08	011,678 EGP	93.2 %
05	07	36 Days	12/08/08	22/09/08	002,090 EGP	93.4 %
06	06	63 Days	06/08/08	21/10/08	005,760 EGP	92.8 %
07	05	20 Days	15/09/08	11/10/08	001,386 EGP	96.6 %
08	07	51 Days	30/08/08	30/10/08	007,250 EGP	95.4 %
09	05	62 Days	03/09/08	17/11/08	003,616 EGP	95.5 %
10	05	57 Days	14/09/08	22/11/08	030,990 EGP	96.5 %
11	07	29 Days	25/10/08	26/11/08	035,430 EGP	83.8 %
12	03	33 Days	19/10/08	25/11/08	056,820 EGP	95.2 %
13	16	72 Days	18/09/08	20/12/08	169,140 EGP	84.0 %
14	16	50 Days	18/09/08	18/11/08	038,440 EGP	84.0 %
15	07	29 Days	25/10/08	26/11/08	017,052 EGP	92.7 %
16	14	57 Days	14/10/08	24/12/08	021,620 EGP	94.5 %
17	05	122 Days	27/10/08	25/03/09	018,545 EGP	91.0 %
18	15	42 Days	09/02/09	30/03/09	015,530 EGP	90.5 %
19	03	23 Days	02/03/09	29/03/09	002,355 EGP	90.0 %
20	15	23 Days	05/03/09	01/04/09	005,738 EGP	89.6 %
21	11	06 Days	23/03/09	29/03/09	001,060 EGP	96.0 %
22	13	36 Days	18/02/09	01/04/09	004,360 EGP	92.0 %
23	06	60 Days	13/10/08	27/12/08	006,640 EGP	90.5 %

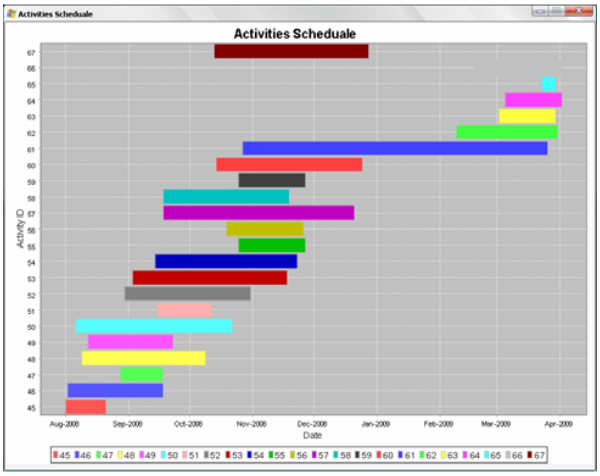

Fig. 19 AMTCROS Bar Chart View of Project Activities

XII. Conclusion

The present research study focused on the multi-objective optimization model for typical construction projects a practical software **A**utomatic **M**ulti-objective **T**ypical **C**onstruction **R**esource **O**ptimization **S**ystem, which named "**AMTCROS**". It was developed to facilitate the optimization of resource utilization in typical construction projects in order to simultaneously minimize project cost and duration while maximizing its quality. The system was developed in four main tasks that led to the development of: 1) A relational database module to store the project data details, project activities details, activities relations, activities resource utilization options, genetic algorithm parameters, and **AMTCROS** software optimization data; 2) A logical module to provide calculations with a seamless integration of the relational database module with the user interface module with modifying module and the multi-objective optimization model; 3) Modifying module is designed to modify the activities durations and relations between sequential activities from one stage to all stages (Modified **C**ritical **P**ath **M**ethod "**CPM**"). That is developed to enable the integration of the logical module with the multi-objective optimization model; and 4) A user interface module to facilitate the input of project and genetic algorithm parameters, as well as the visualization and ranking of the obtained optimal solutions.

References

[1] Hassanen M. M. (1994). "Construction Project Delivery Systems" M. Sc., thesis, Dep. of Civ. Eng., Zagazig University, Egypt.
[2] Duncan W. R. (1987). "A Guide to the Project Management Body of Knowledge" Project Management Institute, North Carolina, U.S.A.
[3] Abdel-Razek R. H. (1996). "Improving Construction Quality in Egypt a Consensus View" Proc., 5th Int. Symposium: Engineering Management, International Project Management Association and Management Engineering Society, Cairo, Egypt, Vol. 2, Session 18.1, pp 1-10.
[4] Abdel-Razek R. H. (1997a). "Construction Quality: How Could We Improve It?" Proceedings of the 3rd Alexandria Conference on Structural and Geotechnical Engineering, Egypt.
[5] Abdel-Razek R. H. (1997b). "How to Improve Quality in Contracting Companies: A Case Study" Proceedings of the 3rd Alexandria Conference on Structural and Geotechnical Engineering, Egypt.
[6] Osman I., and Abdel-Razek R. H. (1996). "TQM-Based performance Measurement System: An Implementation Strategy" Cairo First International Conference on Concrete Structures, Faculty of Engineering, Cairo University, Cairo, Egypt, pp. 5-13.
[7] Abdel-Razek R. H. (1998b). "Quality Improvement in Egypt, Methodology and Implementation" Journal of Construction Engineering and Management, ASCE, 124 (5), 354-360.
[8] Abdel-Razek R. H. (1998a). "Factors affecting construction quality in Egypt: identification and relative importance" Journal of Engineering, Construction and Architectural Management, Vol. 5 (3), pp 220-227.
[9] Abdel-Razek R. H., EI-Dessouki A., and Soliman A. (2000). "Measuring the Quality of Construction" Proceeding of the Inter-Build Colloquium, Cairo, Egypt.
[10] Abdel-Razek R. H., and Hammam M. (2002). "Evaluating the Cost of Poor Quality: A Case Study" Proceeding of the Inter-Build Colloquium, Cairo, Egypt.
[11] Feng C., Liu L., and Burns S. A. (1997). "Using Genetic Algorithms To Solve Construction Time-Cost Trade-Off Problems" J. Comp. In Civ. Engrg., ASCE, 11 (3), 184-189.
[12] Marzouk M., and Moselhi O. (2004). "Multiobjective Optimization of Earthmoving Operations" J. Constr. Engrg. and Mgmt., ASCE, 130 (1), 105-113.
[13] Zheng D. X., Ng S. T., and Kumaraswamy M. M. (2004). "Applying a Genetic Algorithm-Based Multi-objective Approach for Time-Cost Optimization" J. Constr. Engrg. and Mgmt., ASCE, 130 (2), 168-176.
[14] Zheng D. X., Ng S. T., and Kumaraswamy M. M. (2005a). "Applying Pareto Ranking and Niche Formation to Genetic Algorithm-Based Multiobjective Time-Cost Optimization" J. Constr. Engrg. and Mgmt., ASCE, 131 (1), 81-91.
[15] Zheng D. X., and Ng S. T. (2005b). "Stochastic Time-Cost Optimization Mode Incorporating Fuzzy Sets Theory and Nonreplaceable Front" J. Constr. Engrg. and Mgmt., ASCE, 131 (2), 176-1
[16] Senouci A., and Al-Derham H. (2008). "Genetic algorithm-based multi-objective model for scheduling of linear construction projects" Advances in Engineering Software, 39, 1023-1028. journal homepage: www.elsevier.com/locate/advengsoft
[17] Hafez S. M., Korish I. E., Elwany M. H., and Barakat M. A. (1997). "Time Cost Trade-off in Repetitive Projects" Alexandria Engineering Journal, Vol. 36 (1), pp. C39-C47.
[18] Babu G., and Suresh N. (1996). "Project management with time, cost, and quality considerations" European J. Operations Research, (88), 320-327.
[19] Khang D. B., and Myint Y. M. (1999). "Time, cost and quality trade-off in project management: a case study" International Journal of Project Management, 17, (4), 249-256.
[20] El-Rayes K., and Kandil A. (2005). "Time-Cost-Quality Trade-Off Analysis for Highway Construction" J. Comp. In Civ. Engrg., ASCE, 131 (4), 477-486.
[21] Tareghian H. R., and Taheri S. H. (2006). "On the Discrete Time, Cost, and Quality Trade-off Problem" Applied Mathematics and Computation, 181, 1305-1312.
[22] Taheri S. H., and Tareghian H. R. (2007). "A solution procedure for the discrete time, cost and quality trade off problem using electromagnetic scatter search" Applied Mathematics and Computation, (182), 305-312.
[23] Afshar a., Kavek A., and Shoghli O., (2007). "Multi-Objective Optimization of Time-Cost-Quality Using Multi-Colony Ant algorithm" Asian J. of Civil Eng. (Building and Housing), 8 (2), 113-124.
[24] Rahimi M., and Iranmanesh H. (2008). "Multi Objective Particle Swarm Optimization for Time, Cost and Quality Trade-off Problem" World Applied Sciences J., 4 (2), 270-276.
[25] Iranmanesh H., Skandari M., and Allahverdilloo M., (2008). "Finding Pareto Optimal Front for the Multi-Mode Time, Cost Quality Trade-off in Project Scheduling" Proceedings of World Academy of Science, Engineering and Technology, 30, 1307-6884.