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# RESOURCE OPTIMIZATION USING GENETIC ALGORITHM IN THE SIMULATION-BASED PROJECT PLANNING METHOD

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**Abstract:** Resource allocation strategy directly affects project time and cost. Considering an accurate method of planning is required to evaluate the effect of resources, and to optimize resource allocation plan. Current scheduling software programs in industry, like MS Project and Primavera, do not provide resource-oriented planning. The method, therefore, should be capable to automatically update plan, based on different resource allocation scenarios. Automatic optimization tools are also not applicable in the common software programs. Resource allocation plan, therefore, should be enhanced manually by frequently changing resource parameters and checking results, which is difficult, time-consuming, and error-prone. In this research, the Genetic Algorithm is applied on a simulation-based project planning method, to automatically optimize number of resources, based on monthly average budget. In this paper, literature related to the subject will be reviewed, and optimization program will be illustrated. Then modeling process and capabilities of the method will be shown in an actual case study on a residential building.

## 1 INTRODUCTION

Calculating total cost and duration of project in an automatic scheduling method highly depend on number of available resources. In scheduling process, user may change number of available resources several times, to check the effect of each resource on total cost and duration of project. The process of changing number of resources and updating plan by traditional scheduling method is difficult, time-consuming, and error-prone.

Genetic algorithm is a powerful method to optimize plan, by automatically changing number of available resources in a logical process. To easily update plan and achieving best set of resources, availability of an automatic scheduling tool is required. In this research, a simulation-based project planning program is used to update plan automatically through a genetic algorithm process.

## 2 LITERATURE REVIEW

The last quarter of the 20th century has witnessed the introduction and rise of optimization techniques of natural origin, such as genetic algorithms (GAs) (Holland 1975; Goldberg 1989), simulated annealing (Kirkpatrick et al. 1983), and ant colony optimization (Dorigo 1992). These techniques are being applied to engineering problems where classical methods of optimization are inadequate (Toklu, 2002).

The basic GA performs a random search for the optimal solution to a problem by simulating natural evolution and survival-of-the-fittest mechanisms. GA differs from conventional optimization and search procedures in the following four ways, as summarized by Goldberg (1989): (i) GA works with a coding of the parameter (solution) set, not the parameters (solutions) themselves; (ii) GA searches from a population of solutions, not a single solution; (iii) GA uses objective function (fitness function) information, not derivatives or other auxiliary knowledge; and (iv) GA uses probabilistic transformation rules, not deterministic ones.

Basic information about the application of GAs to project scheduling can be found in Wall (1996), Hartmann (1997, 1998), and Kolisch and Hartmann (1999). The genetic algorithms have been applied to optimize construction engineering problems such as resource scheduling (Hegazy 1999a; Li and Love 1997), site layout (Philip et al. 1997), maintenance budget allocation and pavement rehabilitation decisions (Fwa et al. 1995), water network rehabilitation (Halhal et al. 1997), cost of composite floors (Kim and Adeli 2001), and selection of earthmoving fleets (Marzouk 2002; Marzouk and Moselhi 2002).

Chan et al. (1996) combined resource allocation with resource leveling by setting a single equation with the objective of minimizing the difference between resource availability and utilization. In the string representation of GA, they adopted the concept of current float to set the scheduling priority. The current float concept proposed by Shanmuganayagam (1989) was used for elimination of network recalculation, which is the main disadvantage of the total float concept in the critical path method (CPM) analysis.

Hegazy (1999) developed a genetic algorithm procedure to provide a practical optimization model for time– cost trade-off analysis. The procedure searches for the least cost combination of construction methods for the various tasks, considering deadline duration, late completion liquidated damages, early completion incentive, and daily indirect cost. The time-cost trade-off applied by defining different construction methods for each activity and their related cost. Human resource, equipment and materials, therefore, were not defined to perform project activities. As a result, direct resource optimization was not considered in the research.

A GA of Alcaraz and Maroto (2001) was the generalization of the activity list GA of Hartmann (1998). They used the serial schedule generation scheme and included an additional gene that decides whether the activity list is scheduled in a forward or backward direction. From extensive computational experiments based on a standard set of project instances (Kolisch and Sprecher 1997), it was shown that the algorithm provides good performance based on the developed forward-backward crossover techniques. An extended self-adapting genetic algorithm (SAGA) proposed by Hartmann (2002) was developed based on a previous GA (Hartmann 1998). SAGA has been provided with several features: (i) an extended representation of an individual, which includes an additional gene that decides the decoding procedure; (ii) adapted crossover and mutation operators; and (iii) a new method for computing an initial population. Although the result increased the quality of the solutions, an additional computational cost was required.

Toklu (2002) used genetic algorithm to schedule an eight-activity resource-constrained project. A penalty function was used to repair infeasible offspring schedules that the genetic operators may produce. The presented model was designed for applying on small-sized projects, and requires much manual work for modeling large-scale projects.

Marzouk and Moselhi (2003) presented a constraint-based genetic algorithm dedicated to optimizing earthmoving operations. A set of cyclic operations defined to perform an earthmoving project. The authors applied and compared three methods (inversion, linear ranking and nonlinear ranking) to normalize fitness values of chromosome, two methods (roulette wheel and tournament) for chromosome selection, and two methods (discrete and arithmetic) for applying crossover function. The presented method is well-optimized for cyclic operations, but will not be applicable for linear projects with high number of activities, like building construction.

Kim (2009) presented an improved elitist genetic algorithm (GA) for resource-constrained scheduling of large projects. The proposed algorithm allocated multiple renewable resources to activities of a single large-sized project to achieve the objective of minimizing the project duration. Project cost, which is an important parameter in industry, is not considered in this research. Considering budget limitation in scheduling may not result to minimum possible project duration, but is more applicable in industry.

The objective of this research is to optimize resource allocation, considering time and budget limitations, using an automatic genetic algorithm process linked to a simulation-based project planning program. The platform used in this research allows project manager import activities database into planning program, and use resource data to perform optimization. Linking genetic algorithm to the planning program helps manager optimize schedule in a completely automatic process.

## 3 AN INTRODUCTION TO MODELING PROGRAM

In this research a simulation-based construction project management program, developed by the authors (Hadavi and Tavakolan 2016) as MSc. Thesis in University of Tehran, is used to schedule project and generate cost data. Data management comprises three major phases in the program; raw data management, variables management, and results management.

In raw data management phase, building is broken down into elements, project activities are imported (through an automatic extraction from Iran’s Cost Estimation Standard or manually by user), resources required to perform each activity are imported (through an automatic extraction from Iran’s Cost Analysis Standard or manually by user), and cost rates of utilizing resources are imported into model. Then, in variables management phase, relations between activities are defined, number of required resources is entered, number of available resources is assigned to each resource type, and limitations of resource leveling and project calendar are defined. Finally, by running simulation, program calculates project schedule, cost, resource utilization data, and date-sorted material requirements.

On each step of simulation program, remaining possible-to-start activities are sorted by their float. Then the activity with lowest float is selected as highest priority activity to start. Finally, start time and finish time of the activity are calculated by performing a constraint-based simulation. In this method, activities relations and resources availability are considered as constraints to start each activity.

For this program, Microsoft Excel is used to take data and show results. Inputted data is processed through genetic algorithm and constraint-based simulation by VBA coding as Microsoft Excel macros.

## 4 RESEARCH METHODOLOGY

Changing the available resources in a series of successive runs generates a group of trade-off scenarios. The output of the genetic algorithm indicates how allocation of resources may affect final time and cost, data from which the manager may derive a first set of available resources to be employed based on project average monthly financing.

The financing section of program calculates maximum and minimum project times and cost, showing average monthly cost for each one. A genetic algorithm optimizes time versus cost. For the maximum case, a simulation runs with no limitation on available resources for the project duration. In the minimum case, the simulation runs with the minimum required number of each resource. By running these two cases, estimated time, cost and required average monthly finance will be calculated for marginal situations. Using average monthly financing provided by the customer, the program calculates a set of application of resources that most closely matches capable finance.

To reduce total duration of program run, a genetic algorithm with population of 12 for each generation was used. Each chromosome of a population consisted of a series of selected resource utilizations. Each solution was encoded by a series of integers between minimum possible and maximum possible deployment of each resource. By creating 12 candidate solutions, the program runs 12 simulation models. The objective of the genetic algorithm is to minimize the difference between projected cost and available financing. The fitness function of this algorithm is defined below.

[1] Fitness function = |Generated cost – Available financing|

The top three best fitted chromosomes were selected to breed a new generation. Some resources may not affect final results in some situations, and critical resources on each run may differ. A complete uniform crossover and mutation was applied to the top three chromosomes selected from previous generation. The crossover function created six and the mutation created three new chromosomes. These nine chromosomes and top three chromosomes of the previous generation form the new 12-chromosome population of next evaluation. The primary population of the genetic algorithm was created from 12 randomly selected solutions, instead of top three used in other iterations. This process was repeated for the number of requested iterations. The optimum set of available resources will be used as a primary set for simulation run. Using this primary set as a baseline, variables can be changed by the user in subsequent runs of the simulation model to arrive at the best possible case satisfying all aspects of project scope. Figure 1 shows a flowchart of genetic algorithm.

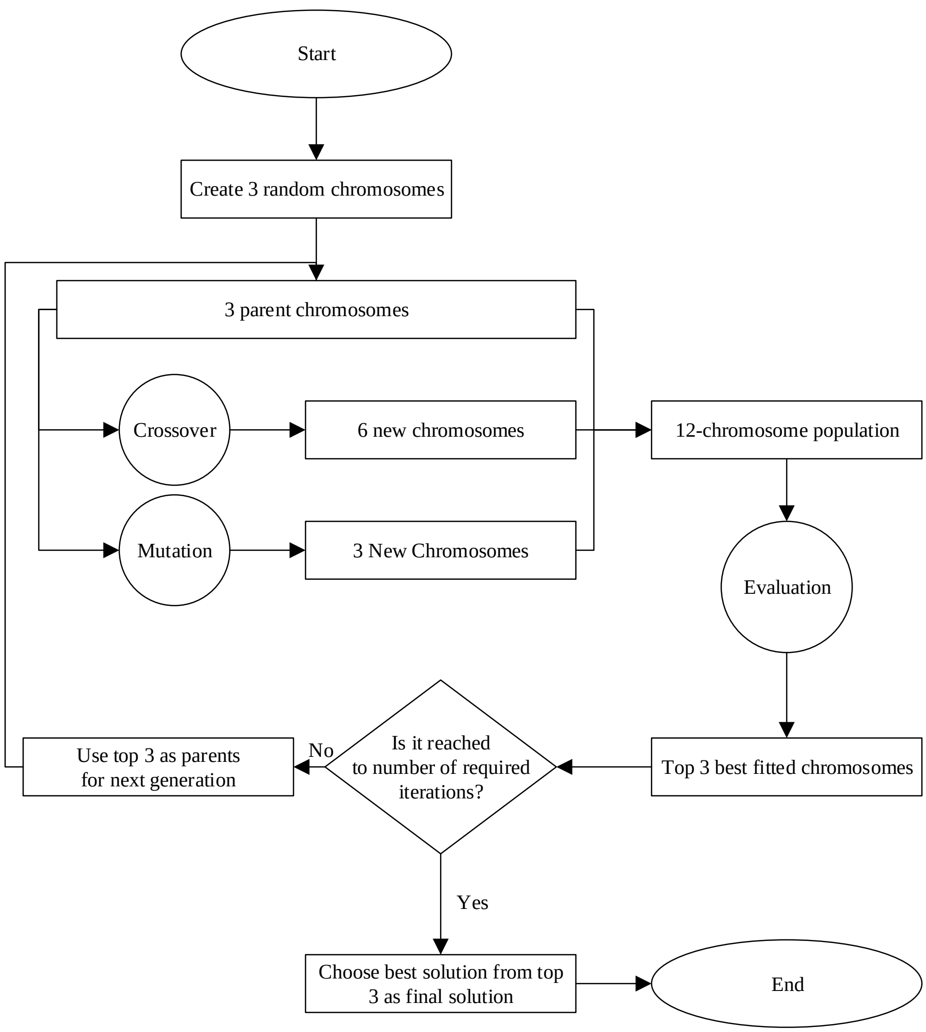


Figure 1: Flowchart of genetic algorithm

## 5 CASE STUDY

Construction of the structure of a residential building in Velenjak, Tehran, was selected to illustrate the modeling process and capabilities of model. The project building comprises two basement floors, a ground floor and five typical floors. Project work was broken down to a manageable level to provide the project manager with detailed results at any level required. As a result, a 176-item work breakdown structure is defined (Figure 2). The WBS of two basements consists of similar items. Number 1 and 2 would be substituted x for basement 2 and basement 1, respectively. The WBS of ground floor and five typical floors is similar to the WBS of basement, with the exception of the ramp item. Numbers 3 to 8 would be substituted for x for ground floor and floors 1 to 5, respectively.

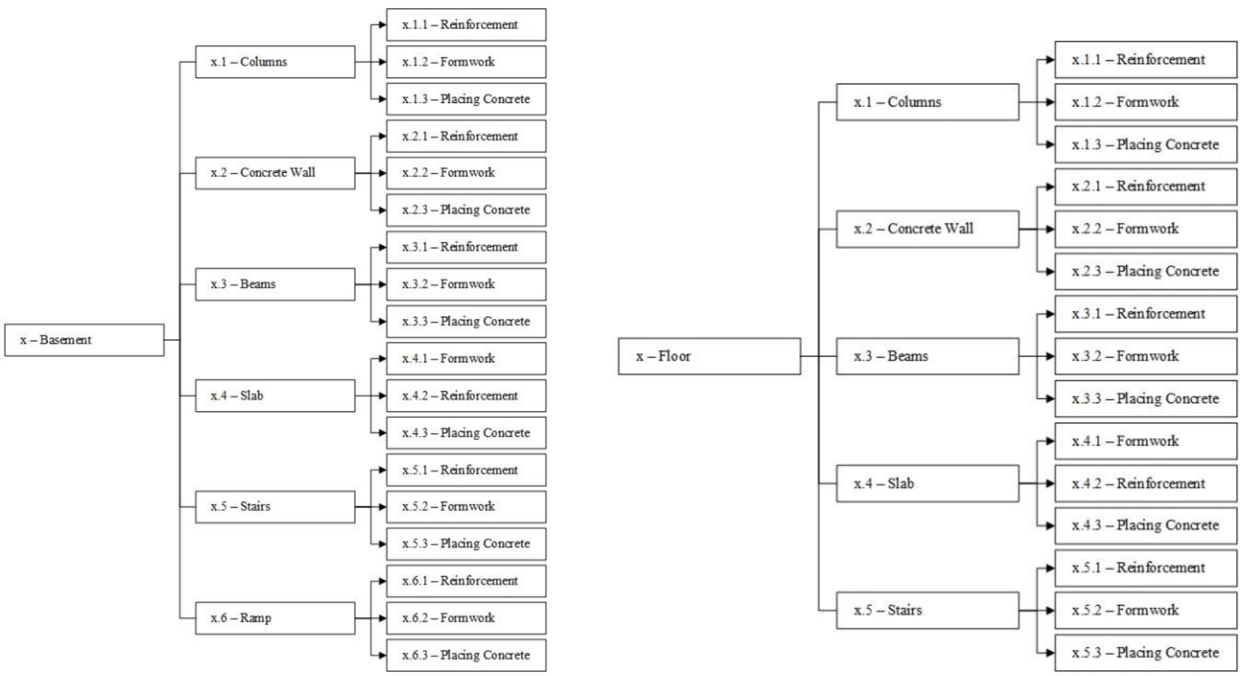


Figure 2: WBS of project

The project work defines 263 activities performed by 1407 entries for the resources database. Excerpts of the activities form and resources forms are shown in Figure 3 and Figure 4, respectively. Values in white cells of the table are by user. Other cells are generated based on imported database and previous entries.

| Activity No. | WBS Code | WBS Title | Element Code | Estimation Code | Estimation Title | Unit | Value | Relations |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.1.1 | Basement 2 \| Columns \| Reinforcement | C1ARL | 11070204 | Reinforcement by steel bars equal or lower than 10mm diameter | kg | 1744.8 | FS 2 |
| 2 | 1.1.1 | Basement 2 \| Columns \| Reinforcement | C1ARH | 11070206 | Reinforcement by steel bars equal or lower than 20mm diameter | kg | 5290.2 | Start 0 |
| 3 | 1.1.2 | Basement 2 \| Columns \| Formwork | C1AF | 11060301 | Metal formwork up to 3.5 meters height | $m^2$ | 122.2 | FS 1 |
| 4 | 1.1.3 | Basement 2 \| Columns \| Placing Concrete | C1AC | 11080106 | Placing 25MP concrete | $m^3$ | 18.7 | FS 3 |
| 8 | 1.2.1 | Basement 2 \| Concrete Wall \| Reinforcement | W1AR | 11070205 | Reinforcement by steel bars from 12mm to 18mm diameter | kg | 187.8 | SS 19 |
| 9 | 1.2.2 | Basement 2 \| Concrete Wall \| Formwork | W1AF | 11060201 | Metal formwork up to 3.5 meters height | $m^2$ | 15 | SS 20 FS 8 |
| 10 | 1.2.3 | Basement 2 \| Concrete Wall \| Placing Concrete | W1AC | 11080106 | Placing 25MP concrete | $m^3$ | 2.5 | SS 24 FS 9 |
| 13 | 1.3.1 | Basement 2 \| Beams \| Reinforcement | B1ARL | 11070204 | Reinforcement by steel bars equal or lower than 10mm diameter | kg | 1550 | FS 14 |
| 14 | 1.3.1 | Basement 2 \| Beams \| Reinforcement | B1ARH | 11070206 | Reinforcement by steel bars equal or lower than 20mm diameter | kg | 4335.5 | FS 7 |
| 15 | 1.3.2 | Basement 2 \| Beams \| Formwork | B1AF | 11060501 | Metal formwork up to 3.5 meters height | $m^2$ | 249.2 | FS 13 |

Figure 3: Excerpt of the activities form

| Res. No. | Act. No. | Res. Code | Resource Type | WBS Code | Estimation Title | Resource Title | Resource Unit | Coeff. | Value Optimistic | Value Most Likely | Value Pessimistic | Number Used |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 14010102 | Human | 1.1.1 | Reinforcement by steel bars equal or lower than 10mm diameter | Simple Worker | Person-Hour | 1.102 | 0.09 | 0.1 | 0.11 | 4 |
| 2 | 1 | 14050101 | Human | 1.1.1 | Reinforcement by steel bars equal or lower than 10mm diameter | Reinforcement Head Worker | Person-Hour | 1.102 | 0.0025713 | 0.002857 | 0.0031427 | 1 |
| 3 | 1 | 14050201 | Human | 1.1.1 | Reinforcement by steel bars equal or lower than 10mm diameter | Reinforcement Skilled Worker | Person-Hour | 1.102 | 0.0041139 | 0.004571 | 0.0050281 | 1 |
| 4 | 1 | 14050202 | Human | 1.1.1 | Reinforcement by steel bars equal or lower than 10mm diameter | Reinforcement Simple Worker | Person-Hour | 1.102 | 0.020565 | 0.02285 | 0.025135 | 1 |
| 5 | 1 | 14050203 | Human | 1.1.1 | Reinforcement by steel bars equal or lower than 10mm diameter | Reinforcement Worker Helper | Person-Hour | 1.102 | 0.041139 | 0.04571 | 0.050281 | 1 |
| 6 | 1 | 23020803 | Equipment | 1.1.1 | Reinforcement by steel bars equal or lower than 10mm diameter | Tractor with Trailer and Driver | Number-Hour | 1 | 0.0040266 | 0.004474 | 0.0049214 | 1 |

Figure 4: Excerpt of the resources form

Default working hours set to eight hours for Saturday through Wednesday, four hours for Thursday, and 0 hour for Friday. The project is set to start September 23, 2015. Financing may be performed at this stage of project. The objective of the financing section is to reach the optimum set of available resource numbers satisfying project average monthly financing and project duration. To propose a set of numbers, genetic algorithm is performed as described in the modeling program. Maximum-resource case and minimum-resource case of this project is calculated as shown in Table 1. Daily cost of this project is 1.5 million rials.

Table 1: Maximum case and minimum case for project total cost and duration

| Case | Required Monthly Finance (Million Rials) | Finish Date | | |
|---|---|---|---|---|
| | | Year | Month | Day |
| Max | 366.6 | 2017 | 1 | 28 |
| Min | 441 | 2016 | 10 | 27 |

As shown in Figure 5, a duration-monthly finance diagram is generated by performing GA for another eight finance values, between maximum case and minimum case for a better perspective of project construction. This diagram is generated by calculating monthly finance of max case, min case and nearest values to 370, 380, 390, 400, 410, 420, 430, and 440 million rials by 20-iteration GA execution.

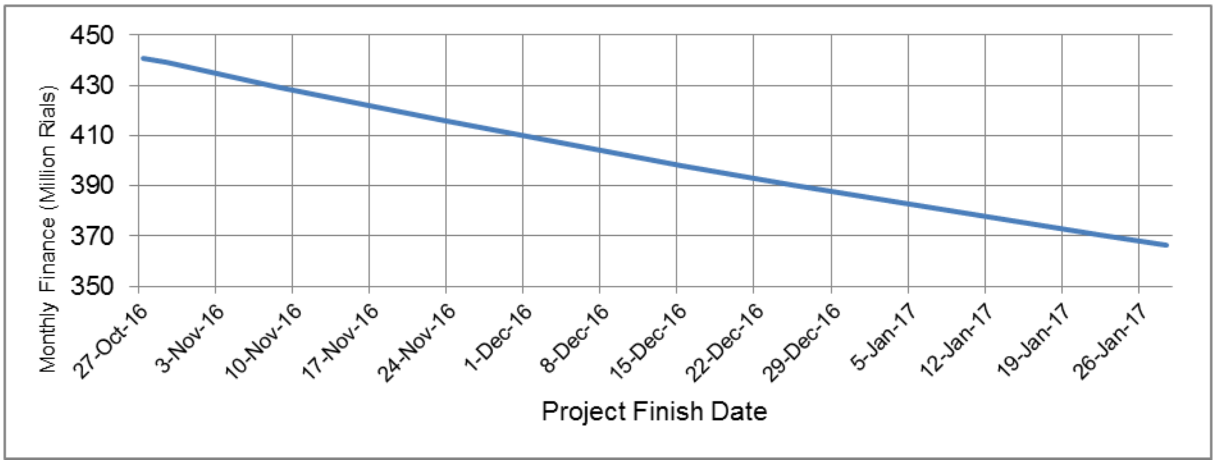


Figure 5: Duration-monthly finance diagram

The user enters possible values for monthly finance by checking the diagram. The program then calculates the set of available resources by a 100-iteration GA execution. Selected monthly finance for this project set to 400 million rials. The proposed available resources are shown on Table 2. This set of numbers will be used for primary run of simulation. Primary result shows that project costs 399.5 million rials per month and finishes on December 13, 2016.

Table 2: Minimum, maximum and proposed number of available resources

| No. | Resource Code | Resource Type | Resource Title | Min | Max | Proposed |
|---|---|---|---|---|---|---|
| 1 | 13040101 | Human | Concrete Machine Operator | 1 | 4 | 4 |
| 2 | 13040802 | Human | Electric Elevator Operator | 4 | 4 | 4 |
| 3 | 13040901 | Human | Hand Roller Operator | 2 | 2 | 2 |
| 4 | 13041401 | Human | Vibration Worker | 2 | 4 | 4 |
| 5 | 14010102 | Human | Simple Worker | 8 | 33 | 11 |
| 6 | 14020102 | Human | Simple Bricklayer | 1 | 1 | 1 |
| 7 | 14040101 | Human | Skilled Form Worker | 3 | 11 | 7 |
| 8 | 14040102 | Human | Simple Form Worker | 3 | 9 | 8 |
| 9 | 14040103 | Human | Form Worker Helper | 6 | 22 | 12 |
| 10 | 14040201 | Human | Skilled Steel Form Worker | 1 | 4 | 4 |
| 11 | 14040202 | Human | Simple Steel Form Worker | 1 | 4 | 3 |
| 12 | 14040203 | Human | Steel Form Worker Helper | 1 | 4 | 3 |
| 13 | 14050101 | Human | Reinforcement Head Worker | 1 | 5 | 3 |
| 14 | 14050201 | Human | Reinforcement Skilled Worker | 1 | 5 | 2 |
| 15 | 14050202 | Human | Reinforcement Simple Worker | 2 | 10 | 8 |
| 16 | 14050203 | Human | Reinforcement Worker Helper | 4 | 19 | 13 |
| 17 | 14060101 | Human | Concrete Skilled Worker | 1 | 4 | 3 |
| 18 | 14060201 | Human | Concrete Mason | 2 | 8 | 8 |
| 19 | 14060202 | Human | Concrete Mason Helper | 1 | 4 | 4 |
| 20 | 14150101 | Human | Skilled Cement Worker | 3 | 3 | 3 |
| 21 | 14220303 | Human | Stone Mason Helper | 2 | 2 | 2 |
| 22 | 22020105 | Equipment | 500l Concrete Mixer | 1 | 4 | 1 |
| 23 | 22020107 | Equipment | 750l Concrete Mixer | 1 | 4 | 4 |
| 24 | 23020101 | Equipment | 3-Ton Truck with Driver | 1 | 4 | 2 |
| 25 | 23020803 | Equipment | 2WD Tractor with Trailer and Driver | 1 | 2 | 1 |
| 26 | 23021102 | Equipment | 2-Ton Hydraulic Dumper with Driver | 1 | 4 | 4 |
| 27 | 24010803 | Equipment | 300 kg Electric Elevator | 3 | 3 | 3 |
| 28 | 25030101 | Equipment | Compactor | 2 | 2 | 2 |
| 29 | 26020502 | Equipment | 150A to 250A Welding Machine | 2 | 4 | 2 |
| 30 | 28100201 | Equipment | Vibrator Machine | 2 | 4 | 2 |

## 6 CONCLUSIONS

In this research, optimization of resource allocation plan performed, by linking genetic algorithm to a simulation-based project planning program. The proposed method considers time limitation and budget limitation to plan project. For each run of genetic algorithm, the set of proposed number of resources is sent to program for execution of constraint-based simulation. Project schedule and total cost will be calculated by considering resource limitation and activities relation in a constraint-satisfaction process. The automatic process of planning helps managers implement proposed method, easier than past studies. Also, it provides a great view of time-cost trade-off by running genetic algorithm for various budgets. The proposed method successfully implemented on a residential building to optimize resource allocation plan of a 263-activity project. The results showed that project will be finished in 15 months, considering a monthly average budget of 400 million rials.

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