Resource Utilization Optimization using Genetic Algorithm based on Variation of Resource Fluctuation Moment for Extra-Large Building Renovation

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Abstract. This paper compared optimizing resource utilization using Genetic Algorithm (GA) based on variation of resource fluctuation moment (*Mx*) for extra-large building renovation. The *Mx* variable, as determined by resource demand on day squared, has a large effect on the result of multi-objective optimization. In this research, an *Mx*-based optimization model targeting five variables for resource utilization was proposed. In addition, the proposed method is flexible in that the construction planners could specify predecessors or preferences for optional construction sequences then the more efficient optimal scheduling maybe obtained. Three activation functions for *Mx* were considered, namely *Mx*, $\sqrt{Mx}$ and *Mx /1000*. In this work, the models in consideration were applied to real data from the university main library building renovation projects which consisted of 251 activities. The contractor's work plan was used as the initial scheduling for the optimization process. When comparing the experimental results from all 3 models, it can be seen that the form $\sqrt{Mx}$ and *Mx/1000* are shown to be more suitable in optimizing resource utilization through GA method in extra-large building renovation.

1 Introduction

Extra-large scale renovation projects have different features compared to new building projects. They consist of complex activities network and various kinds of resources are involved. In addition, renovations are often carried out in an existing building that remains in operation. Unique challenges that are related to renovation projects are, for example, an additional level of uncertainty (e.g. unexpected problems that only appear when the demolishing phase has started, the unavailability or inaccuracy of existing as-built drawings) and particular management issues (e.g. due to limited working space, difficulty in managing the interaction between the construction team and users) [1-2]. Such characteristics increase the complexity inherent to construction settings. Hence, more flexible planning [3-4] unique to the extra-large scale renovation projects are obligatory. To improve resource management of projects, resource utilization problems have been studied intensively [5-12]. However, previous approaches are often not able to deal with the dynamic nature of real-world projects. Accordingly, the model of planning should be able to adjust to fit project characteristics. Resource fluctuations are generated in the development process of project schedules. T. Hegazy (1999) developed a practical procedure for searching a near-optimal solution to resource allocation and leveling. The GA-based model minimizes total project duration under resource constraints while also minimizing the fluctuations in daily resource demands and the resource utilization period. K El-Rayes and D. H. Jun (2009) developed resource leveling and optimization model by directly measure and minimize the resource fluctuations on construction productivity and cost, for instance. Despite the large amount of literature in GA-based optimization, not many studies have considered multi-objective functions [9, 11, 14] Due to the complexity of renovation projects, few have attempted to use data from dynamic real-world scenario as the input data. A recent approach called multi-objective optimization model was developed to simultaneously optimize resource utilization for extra-large renovation and construction projects. In this approach, the resource fluctuation moment (*Mx*) is a key variable that has a large effect on the overall multi-objective function. In this work, three

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activation functions for the resource fluctuation moment are considered and new *Mx*-based optimization models are developed and tested against real-world data to compare their performance. The proposed method is flexible in that the construction planners could specify predecessors or preferences for optional construction sequences then the more efficient optimal scheduling maybe obtained. In addition, the approach is designed to allow decision makers to be able to adjust the solutions to meet their satisfaction once the optimal schedule is obtained. Lastly, a macro program was written to automate the GA procedure and a case study was demonstrated.

2 Literature Review

The objective of the proposed GA-based models is to find the optimal schedule that maximizes resource utilization efficiency. GA has been widely applied as a global optimization method in scheduling by many researchers in the field of construction. The performance of GA methods is stable and reliable for schedule optimization [15-18]. In addition, the strength of these methods lies in their ability to identify optimal and near optimal solutions in large search space [12]. GA has also been employed by many studies to solve problems with multi-objective function as the technique demonstrates flexibility when applied to diverse complex problems, especially for schedule optimization [18-19].

To optimize resource leveling and allocation in construction project, many attempts have been made to employ GA as an optimization tool [5-12]. Researchers have proposed variables for calculating the resource leveling such as Minimum moment method (*Mx*) [6], Resource and Rehire *(RRH)*, Resource Idle Day *(RID)* [13]. The studies on RRH and RID attempt to minimize the number of resource and rehire and number of resource idle day. A. Intarasap (2013) proposed resource leveling model that leads to an optimal schedule by reviewing relationship options [10]. Resource Allocation generates appropriate resource utilization solution by rescheduling project activities within the minimize project duration [17, 20]. Both techniques helped in developing a new measurable for multi-objective optimization models and minimizing the undesirable resource fluctuations in order to maximize resource efficiency and minimize project duration, along with the resource availability constraints [21]. In this paper, ideas from previous literature are combined into a multi-objective optimization process that considers resource allocation and resource leveling problems simultaneously. The paper compared resource utilization optimization using GA based on variation of resource fluctuation moment (M_x) for extra-large building renovation. This optimization function is designed to incorporate planner-defined weights in order to minimize the variables and cope with real world dynamic data.

3 Mathematical Formulation and Methodology

GA has been the subjects of interest in many studies. Comparing to other optimization techniques such as ant colony or particle swarm, GA has been widely used as a global optimization method in scheduling. The performance of the GA method is stable and reliable for scheduling optimization and have been verified by many researchers in the field of construction [18]. In this work, GA was applied to real data from the university main library building renovation project which consist of 251 activities. Specifically, GA was employed to find the optimal schedule that minimizes resource fluctuation, resource undesirable fluctuation, resource peak demand and project duration based on variation of resource fluctuation moment (*Mx*). The *Mx* variable was entered into three activation functions, namely: *Mx*, $\sqrt{Mx}$ and *Mx/1000*, as shown in Eq. (1), (2) and (3).

Objective function

$$\text{The objective function} = Min(w_1Mx+w_2RRH+w_3RID+w_4MRD+w_5T) \quad (1)$$

$$\text{The objective function} = Min\ (w_1\sqrt{Mx} + w_2RRH+w_3RID+w_4MRD+w_5T) \quad (2)$$

$$\text{The objective function} = Min\ (w_1Mx/1000+ w_2RRH+w_3RID+w_4MRD+w_5T) \quad (3)$$

The fluctuations can be classified based on their impact on the efficiency of resource utilization into five variables: resource fluctuation Moment *(Mx)*, Release and Re-Hire *(RRH)*, Resource Idle Days *(RID)*, Maximum Resource Demand *(MRD)* and Total time project *(T)*, where w = preference weight.
The moment *Mx* is calculated by summing the daily moments, as shown in eq.4

$$M_x = \sum_{j=1}^{n} \left(Resource\ Demand_j\right)^2 \quad (4)$$

where n = working day number of the project's finish date.

RRH represents the total amount of resources that need to be temporarily released during low demand periods and rehired at a later stage during high demand periods [8]. Where H = daily resource demand; MRD = maximum resource demand; HR = total daily resource fluctuation and each term are quantified as follows,

$$RRH = H - MRD = \tfrac{1}{2} \times HR - MRD \quad (5)$$

$$HR = [r_1 + \textstyle\sum_{t=1}^{T-1} |r_t - r_{t+1}| + r_T] \quad (6)$$

$$MRD = Max(r_1, r_2, \dots, r_T) \quad (7)$$

RID represents the total number of idle and nonproductive resource days caused by undesirable resource fluctuations during the entire project duration.

$$RID = \sum_{t=1}^{T} [\, Min\{Max(r_1, r_2, \dots, r_t) Max(r_t, r_{t+1}, \dots, r_T)\} - r_t] \quad (8)$$

Where r_t = resource demand on day

Decision Variable

$$0 \le S_i \le TF_i \quad (9)$$

Where S_i = Shift days of activity i; TF_i = Total Float of activity i

$$0 \le x_{ihg} \le 1 \quad (10)$$

Where x_{ihg} = Predecessor option between h or g of activity i

Constraint Function

$$Max(FT_i) \le T \quad (11)$$

Where FT_i = Finish Time of activity i; T = Project duration

$$r_{xt} \le MRA_x \quad (12)$$

Where r_{xt} = resource demand type-x on day t; MRA_x = Maximum Resource Availability of resource type x

This study considers four resource types i.e., general worker skilled carpenters, sanitary plumbers and electricians.

Optimization process

Optimization process is explained in fig.1. The solution finding procedure is explained with the following main steps: 1) Initialization and 2) GA operation; and described in details in the following sections.

Initialization

A macro program based on Visual basic was written to automate the optimization process for supporting the real-world renovation scheduling. This program is based on the predecessor diagram method (PDM), there are four relationship constraints: Start to Finish (SF), Start to Start (SS), Finish to Start (FS) and Finish to Finish (FF). In this study, extra constraints, i.e., overlapping time (lead time and lag time) and project calendar constraints, i.e., excepting date and project agreement date, are also included. This results in the reasonable project scheduling for real world scenario generated by the proposed process. The computation procedure of in this part is performed using the following seven steps (Fig. 1).

1. A baseline schedule providing required data from Microsoft project is imported to the optimization module.
2. Set initial constraints – Time constraints and resource constraints. Model's parameters including number of constraints and independent variables and project's parameters including number of activities, precedents and successors of activities, resources availability during project execution (i.e., resource constraints) are collected. Setting up the project calendar according to contract constraints – time, special agreements.
3. According to PDM, data or each activity from baseline schedule e.g., duration and daily resource demand are used to calculate start time (ST_i), finish time (FT_i), late start time (LS_i), late finish time (LF_i) and the total float (TF_i) for each activity in the project based on time constraints using Eq.11 and calculate daily resource demands (r_t) based on resource constraints using Eq.12.
4. Set initial decision variables
   4.1. Set1: set lower and upper bound (S_i = 0 to Maximum shift time of activity)
   4.2. Set2: Define predecessor option (X_g) and set lower and upper bound (X_{ihg} = [0,1])

   In this step, because of the typical characteristic of renovation project as mentioned prior (i.e., additional level of uncertainties and particular management issues), decision variable Set2 is proposed. Predecessor option is defined (X_g) and the optimal scheduling is now processed by considering both Set1 and Set2 options. By considering Set2 option, the more efficient optimal scheduling. in terms of the interactive planner's viewpoint is obtained
5. Calculate initial objective function value (Eq.1, 2 and 3).
6. Define evolution weights for multi-objective optimization variables. Preference weights for minimizing each resource are calculated using pairwise technique of Analytical Hierarchy Process (AHP) and normalize weight method. These weights allow decision makers to incorporate the priority of each objective into decision making.
7. Input GA parameters i.e., number of populations, number of generations, selection technique, crossover rate, mutation rate and termination criteria.

GA Operation

The following sections describe the functioning of GA in detail.

1. After initial objective function value is saved, initialization process can be completed by randomly generate populations and selecting the appropriate population number 1. As shown in Fig.2, each chromosome comprises a number of blocks which represent the individual decision variables of the problem, that are comprises of binary bits could encode integers, real values, sets or what was appropriate to the problem. In this study, there are

two sets of decision variables – shift time and predecessor option. In addition, total number of activities for all decision variables is 254.

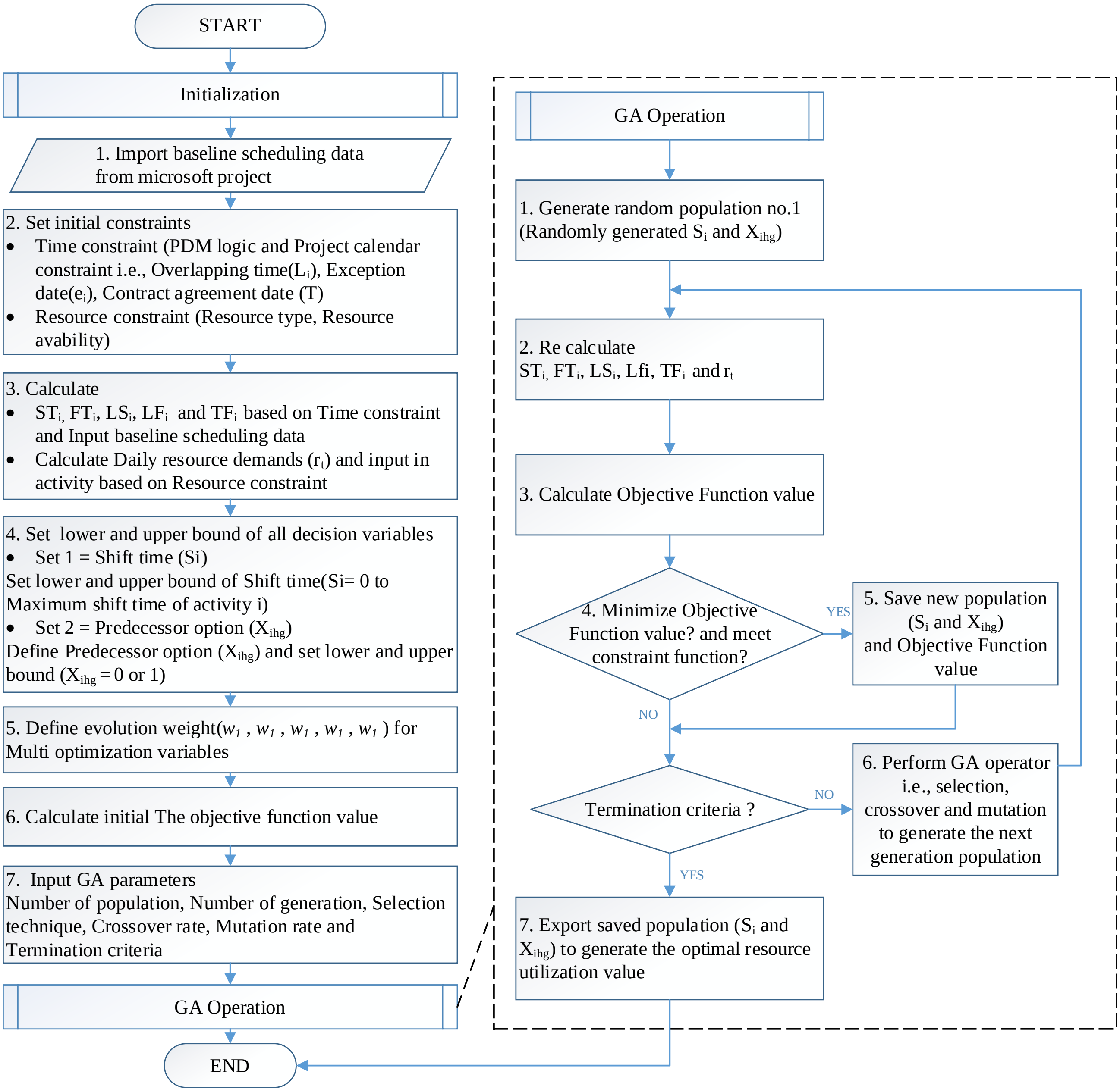


Figure 1. Optimization process

As suggested by S.RAO(2009), if the number of design variables is N, usually the size of the population is taken as 2N to 4N [16].The population size in this study is 500.

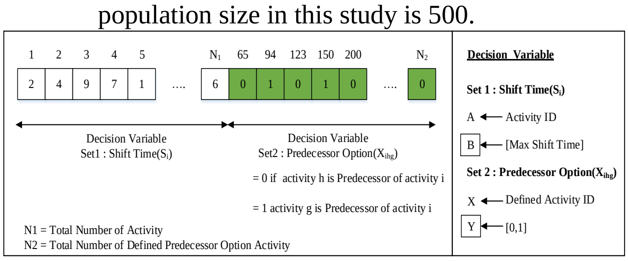


Figure 2. Chromosome structure for GA operation

2. According to selected population number 1 (S_i and X_{ihg}), start time (ST_i), finish time (FT_i), late start time (LS_i), late finish time (LF_i) and the total float (TF_i) for each activity in the project are recalculated.
3. Calculate objective function value from Eq. 2,3 and 4.
4. The fitness of its chromosome is evaluated by the relative improvement over the previous iteration as computed by the objective function. The smaller this fitness value, the more fit the chromosome is. In this step, the constraint functions are also checked by Eq. 11 and 12.

5. New population and objective function value that are saved and the termination criteria is checked. In this study, 20,000 generations are taken as terminal condition during evolution.
6. In performing GA operator, the next generation population is created based on the calculation of fitness values using GA i.e., selection, crossover and mutation. Chromosome selection technique depends on a rank-based mechanism. Crossover is performed using a uniform crossover routine i.e., two groups are formed by randomly selecting items to be in one group or another. Mutation is performed by sapping the positions of some variables in the chromosome. The number of swaps performed is increased or decreased proportionately to the increase and decrease of the mutation rate setting (from 0 to 1) [22].
7. Export saved population to generate the optimal resource utilization value.

Experimental design

The performance of the proposed *Mx*-based optimization model which involved three different activation functions, namely *Mx*, $\sqrt{Mx}$ and *Mx /100*, is evaluated based on real data from the renovation of university main library building projects in this section. The contractor's work plan was used as the initial scheduling for optimization process. Based on this information, the schedule is optimized using GA process show in fig.2. The parameter settings are summarized as follows: population size = 500, termination conditions = 20,000, crossover rate = 0.5, mutation rate = 0.1. Two experiments were conducted by the present models considering two separate processes: 1) Equally assigned priority for every variable with decision variable Set1 and 2) Equally assigned priority for every variable with decision variable Set1 and Set2.

Equally assigned priority for every variable with decision variable Set1

This was tested by comparing the priorities of the five variables factors (i.e., Sum of squares method *(Mx)*, Resource and Rehire *(RRH)*, Resource Idle Day *(RID)*, Maximum Resource Demand *(MRD)* and Total Time Project *(T)*) in pairs (Pair Wise Comparison) one by one, giving priorities when compared. All variables are equal. Numerical value = 1 will have a priority for all variables. Compare it to 1/1. Then use a matrix table as a tool to weigh its importance. When calculating Normalized Matrix of the matrix, the weight of the five variables factors = 0.20. Then, the weight is applied to those objective functions which are then optimized with GA. As a result, new values for those 5 variables and objective function are obtained. The new value shows the improvement of resource utilization.

Table 1. The optimization result using *Mx* model

Model *Mx*	Weight	0.2	0.2	0.2	0.2	0.2	Minimize
Scheduling Type	Type of resource (r_x)	*RRH*	*RID*	*Mx*	*MRD*	*T*	Objective Function
Baseline Scheduling	General worker	75	25465	210027	50	704	
	Skilled carpenter	28	14134	46332	26	704	
	Sanitary-Plumber	19	3744	34122	19	672	
	Electrician	38	6277	58435	17	716	
	Total resource	227	29901	1009040	78	716	207992.40
Optimized Scheduling	General worker	90	24573	196321	48	720	
	%diff from baseline	20.00%	-3.50%	-6.53%	-4.00%	2.27%	
	Skilled carpenter	64	14466	41364	26	720	
	%diff from baseline	128.57%	2.35%	-10.72%	0.00%	2.27%	
	Sanitary-Plumber	37	2954	29662	14	720	
	%diff from baseline	94.74%	-21.10%	-13.07%	-26.32%	7.14%	
	Electrician	43	7103	58809	18	720	
	%diff from baseline	13.16%	13.16%	0.64%	5.88%	0.56%	
	Total resource	263	28071	955474	74	720	196920.40
	%diff from baseline	15.86%	-6.12%	-5.31%	-5.13%	0.56%	**-5.32%**

Table 2. The optimization result using $\sqrt{Mx}$ model.

Model √*Mx*	Weight	0.2	0.2	0.2	0.2	0.2	Minimize
Scheduling Type	Type of resource (r_x)	*RRH*	*RID*	√*Mx*	*MRD*	*T*	Objective Function
Baseline Scheduling	General worker	75	25465	458.29	50	704	
	Skilled carpenter	28	14134	215.25	26	704	
	Sanitary-Plumber	19	3744	184.72	19	672	
	Electrician	38	6277	241.73	17	716	
	Total resource	227	29901	1004.51	78	716	6385.30
Optimized Scheduling	General worker	76	25471	456.84	50	705	
	%diff from baseline	1.33%	0.02%	-0.32%	0.00%	0.14%	
	Skilled carpenter	42	12824	208.42	24	720	
	%diff from baseline	50.00%	-9.27%	-3.17%	-7.69%	2.27%	
	Sanitary-Plumber	27	3738	172.62	16	675	
	%diff from baseline	42.11%	-0.16%	-6.55%	-15.79%	0.45%	
	Electrician	38	5610	243.67	16	719	
	%diff from baseline	0.00%	-10.63%	0.80%	-5.88%	0.42%	
	Total resource	202	27232	995.04	74	720	5844.61
	%diff from baseline	-11.01%	-8.93%	-0.94%	-5.13%	0.56%	**-8.47%**

Table 3. The optimization result using *Mx*/1000 model.

Model *Mx/1000*	Weight	0.2	0.2	0.2	0.2	0.2	Minimize
Scheduling Type	Type of resource (r_x)	*RRH*	*RID*	*Mx/1000*	*MRD*	*T*	Objective Function
Baseline Scheduling	General worker	75	25465	210.03	50	704	
	Skilled carpenter	28	14134	46.33	26	704	
	Sanitary-Plumber	19	3744	34.12	19	672	
	Electrician	38	6277	58.53	17	716	
	Total resource	227	29901	1009.04	78	716	6386.21
Optimized Scheduling	General worker	81	25445	209.14	50	705	
	%diff from baseline	8.00%	-0.08%	-0.42%	0.00%	0.14%	
	Skilled carpenter	41	12846	45.80	24	720	
	%diff from baseline	46.43%	-9.11%	-1.14%	-7.69%	2.27%	
	Sanitary-Plumber	22	1879	31.20	13	672	
	%diff from baseline	15.79%	-49.81%	-8.56%	-31.58%	0.00%	
	Electrician	38	5615	58.93	16	720	
	%diff from baseline	0.00%	-10.55%	0.67%	-5.88%	0.56%	
	Total resource	199	27234	989.65	74	720	5843.33
	%diff from baseline	-12.33%	-8.92%	-1.92%	-5.13%	0.56%	**-8.50%**

Table 1, 2 and 3 showed the detailed result of the optimization. They used *Mx*, $\sqrt{Mx}$ and *Mx /1000*, respectively. The new value shows the improvement of resource utilization. The experiment results are as follows: Objective function value compared to initial scheduling Model *Mx* improve by 5.23%, Model $\sqrt{Mx}$ improve by 8.47% and Model *Mx/100* improve by 8.50%.

Fig. 3 presented the resource utilization efficiency generated by the optimization functions with activation functions (Eq.1, 2 and 3). The results from Eq.1, Eq.2 and Eq.3 considering *Mx*, $\sqrt{Mx}$, and *Mx/1000*, respectively. Each line shown in the figures are from now denoted *Mx*, $\sqrt{Mx}$, and *Mx/1000*, correspondingly. $\sqrt{Mx}$, and *Mx/1000* show a similar trend and is 3.2% more efficient than *Mx*. In addition, they required less generation to reach optimal resource utilization. The plot also reveals that while $\sqrt{Mx}$ jumps from about 0.48 to 0.95 at the 1,191st generation at point B and *Mx/1000* jump from about 0.48 to 0.95 at the 1,535th generation at point C, *Mx* slowly climb up from 0.25 to 0.60 at the 12,020th generation at point A.

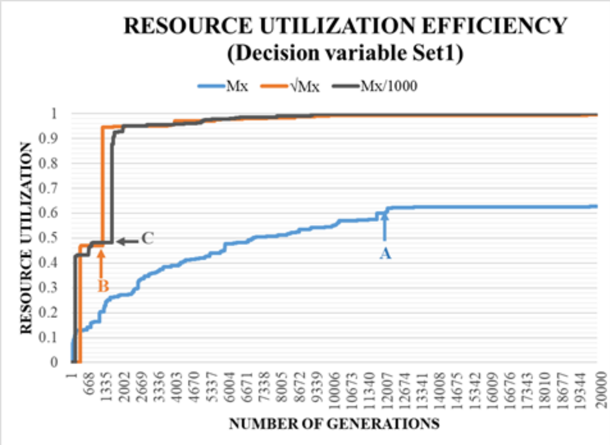


Figure 3. Optimization results of Equally assigned priority for every variable with decision variable Set1

Equally assigned priority for every variable with decision variables Set1 and Set2

In this part, predecessor option (X_g) is defined and Set2 decision variable start its function. In renovation project, the construction phases are normally considered based on working spaces e.g., each floor, and there is a predecessor connecting each phase. Fig.4 illustrates initial predecessor (X_h) where construction sequences start with 4th fl.,3rd fl., 2nd fl. and 1st fl. with basement fl., aka. initial scheduling. Taken into account the suggestion of decision maker, predecessor option (X_g) where optional construction sequences start with 4th fl., 1st fl. with basement fl., 3rd fl. and 2nd fl., is also presented in Fig.4.

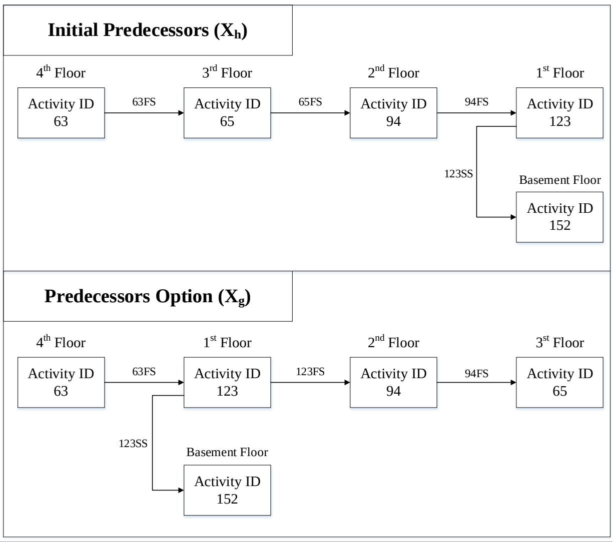
Comparing objective function values with initial scheduling, the experiment results are as follows:

Model *Mx* adopted initial construction sequences: Objective function value improved by 5.61%,

Model $\sqrt{Mx}$ adopted optional construction sequences: objective function value improved by 63.51% and

Model *Mx/1000* adopted initial construction sequences: Objective function value improved by 64.51%.

Therefore, the results from optimal construction sequences show better improvement on resource utilization efficiency than the initial ones. Considering in terms of activation functions, the rapid convergence may be obtained because Mx has been reduced its effect on Multi objective optimization model by considering in terms of $\sqrt{Mx}$, and Mx/1000.



ID	Activity (X_i)	Floor	Initial Predecessors (X_h)	Predecessors Option (X_g)
63	Durable goods and made to order work on the fourth floor	4th	-	-
65	Demolition and clearing work on the 3rd floor (Dismantled)	3rd	63FS	94FS
94	Demolition and clearing work on the 2nd floor (Dismantled)	2nd	65FS	123FS
123	Demolition and clearing work on the 1st floor (Dismantled)	1st	94FS	63FS
152	Durable goodsprocurement or order work on the 1st floor	Basement	123SS	-

Figure 4 Initial and optional construction sequences

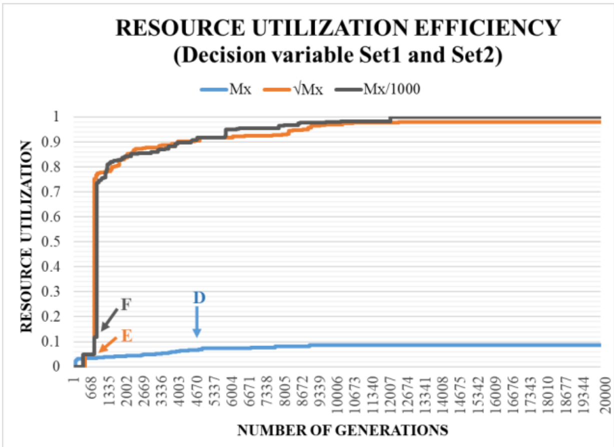


Figure 5. Optimization results of Equally assigned priority for every variable with decision variables Set1 and Set2

Figure 5. showed that using $\sqrt{Mx}$, and *Mx/1000* made resource utilization 91.3% more efficient than using *Mx*. In addition, they required less generation to reach optimal resource utilization. We could see at point E that $\sqrt{Mx}$ jump from about 0.05 to 0.78 at the 773rd generation and at point F that *Mx/1000* jump from about 0.11 to 0.75 at the 865th generation whiles *Mx* slowly climb up from 0.03 to 0.69 at the 4,876th generation at point D.

Comparing the experimental results from all three models, it can be seen that the model using the form $\sqrt{Mx}$ and *Mx/1000* yield better improvement in resource utilization, therefore the form $\sqrt{Mx}$ and *Mx/1000* are shown to be more suitable in optimizing resource utilization through GA method in extra-large building renovation.

4. Conclusion

Five new metrics for resource leveling and a two optimization models were developed, comparing with existing *Mx* model to maximize the efficiency of resource utilization in Extra-Large building renovation. The model is designed to search for optimal and practical schedules that minimize undesirable resource fluctuation while simultaneously minimizing the resource peak demand. The model is developed in two modules which are initialization module and GA – based optimization module. The performance of the proposed *Mx*-based optimization model which involved three activation functions, namely *Mx*, $\sqrt{Mx}$ and *Mx /1000*, is evaluated. The experiment results show the improvement in resource utilization. For decision variable set1(shift time), we obtained 8.47% and 8.50% improvement by using $\sqrt{Mx}$ and *Mx/1000* models, respectively. In addition, for the set1 and set2 (Predecessors option), we obtained 63.51% and 64.51% from $\sqrt{Mx}$ and *Mx/1000* models, respectively. This should prove useful to construction planners and schedulers and can contribute to enhancing the efficiency of resource utilization and improving construction productivity.

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