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Improved Tabu Search Algorithm Application in RCPSP

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***Abstract*—The research will focus on investigating multi-resource allocation optimization problem. Also, instead of using traditional Tabu Search(TS) algorithm and the other Artificial Intelligence（AI） based heuristic approaches solving such kind of problems, this research develops an modified TS model to solve the problems described above. The research makes some improvement on the traditional TS models. The model can effectively provide better result of construction duration compared with traditional TS based search techniques and Artificial Intelligence（AI）based approaches.**

***Keyword:* multi-resource project scheduling; project management; Tabu Search**

Introduction

After the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM) were developed successively, the project resource scheduling problem was subject to more attention. Although PERT/CPM and other related scheduling technologies have already been widely applied in the project planning and control problem, PERT/CPM plans the project scheduling only in respect to the aspect of time. However, it does not consider the factor of resource constraints so that its usability is constrained. In recent years, due to the growing scarcity of resources, it has become pertinent to discuss how to most efficiently utilize the constrained resources in this project, reduce unnecessary cost, and obtain the largest economic value. Therefore, the construction time interval of each activity for the project activity must be efficiently arranged. Thus, the project resource constrained scheduling problem (RCPSP) is a very important issue to investigate.

RCPSP is (non-deterministic polynomial-time) NP-Hard. In the early stage, during solving of the RCPSP, most researchers still used to utilize the traditional heuristic rule to solve this problem. This rule basically took the mode of one by one analysis to solve problems according to the priority rules developed by other scholars.

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It was found that the solution quality was sometimes worse and the preferred solution was often achieved without this sort of priority. If one wanted to get the optimal solution, it may result in much longer execution time. Therefore, the way how to obtain a near optimal solution efficiently without sacrificing the solution quality is important issue to investigate in solving NP-Hard problem. Thus, the Tabu Search (TS) method, a tool to solve the optimization problem, could be expected to be applied in this research to solve the project multi-resource scheduling problem and obtain the optimal solution of this problem. TS have been proved that can get a good performance for solving combinatorial optimization in many areas. Sometimes, it can obtain the better solution quality than some heuristic algorithm in some specified problems. The study will implement TS's concept as basis to develop a new algorithm to solve RCPSP in construction projects.

Considering the constrained resources, there are two objectives of the project scheduling: (1) to make resource utilization of the project efficiently to reduce the possibility of delay in the project when the resource is limited; (2) to make resource utilization of the project more effectively to achieve a better financial management performance, reduce unnecessary cost and increase the revenue of the project.

Various modern heuristic algorithms have recently been developed. There are comprehensive related researches within the other industry's field, obtaining valuable achievements. One of the well-implemented heuristic algorithms is Tabu Search (TS). TS was first presented by Glover in 1997 and was applied in solving the integer programming, although it was not completely proposed until 1986. It is a solution-search algorithm that can conquer area optimization by guiding area search.

The related study that the TS method was applied to in the scheduling optimization also had some achievements. Valls, Vicente, et al. (1998) presented, when the TS method was applied to the standardization scheduling optimization under the condition of a batch of activities, procedures and time of two simple and paralleled standardization. [2] Its objective is to minimize the required time for scheduling. Vinicius et al. (1999) applied the TS method into the scheduling problem to search the minimal total delay while many scholars utilized the minimal total delay production span and multi-activities scheduling in the small-size shop grouping [3]. The TS method was widely applied to solve the various kinds of combinatorial optimization problems in the industrial engineering area and other areas. In these results of the studies even showed that, in some problems, both solution quality and efficiency of evaluation of the TS method was more excellent than that of the GA and other algorithms.

The TS algorithm in RCPSP

The objectives of this RCPSP model are divided into two parts, the first objective is the minimal duration for construction project, that is, under the condition of resource constraints, it is better if the construction completion time limit is shorter; the second objective is the smoothest daily resources consumption. The constraint condition is that the daily consumption of all resources of the activity must be less than or equal to its maximal daily resource supply volume, and its objective is the sequence of resources for each activity. Thus, the structure of the solution is a sequential arrangement structure that each activity utilizes the resources, and the neighborhood solution structures utilize the swap move and the insert move respectively; the Tabu List uses the activity item memory structure of the short-term memory. The following sections will describe the details of each item above.

Establish the objective functions

The objective functions for the RCPSP's model are:

Objective function 1:

$$Min\{Max\ F_i\} \quad \text{.........(equation 1)}$$

$$S.T.\quad S_i = MAX\ F_{bi}$$
$$F_i = S_i + T_i$$
$$R_{kj} \le C_{kj} \quad \text{....... (equation 2)}$$

i: Identification number of each activity of the project.

b: Identification number of the precedent activity of the specific activity of the project.

j: Identification number of each resource type of the project.

K: the k^{th} day.

F_i: the earliest finish time of activity i.

F_{bi}: the earliest finish time of the precedent activity b of the activity i.

S_i: the possible earliest starting time of activity i.

T_i: the duration of activity i.

R_{kj}: the quantity demanded of the resource j on the k^{th} day.

C_{kj}: the quantity constrained of the resource j on the k^{th} day.

Objective function 2:

$$Min \sum_{j=1}^{m} \{[\sum_{i=1}^{n} R_{ij}^{\ 2} + \sum_{i=2}^{n} (R_{ij} - R_{(i-1)j})^2] \times W_j\} \quad \text{(equation 3)}$$

i: Represent the i^{th} working day

j: Identification number of the resource type of the project

R_{ij}: Quantity demanded of the resource j on the i^{th} working day

W_j: Weight of the resource j (its value is determined according to the importance of its resource)

n: Total optimal project duration on the condition of the resource constraints

m: All resource project days

Starting solution of the resource restraints scheduling based on the TS method

In the 8 kinds of methods presented by Moder[4], is Research takes the heuristic method—MINSLK as the starting solution of the resource constrained/allocation for the TS method.

A simple heuristic method is generally used as the starting solution of the TS method, such as MINSLK, LFT and etc from Moder's research [4], it is observed that the rule of MINSLK is better than other heuristic algorithms. Therefore, this research utilizes the MINSLK rule to determine the priority of the resource constrained allocation. The flow of obtaining the starting solution is shown in Figure 1.

The neighborhood solution structure of the resource constraints scheduling based on the TS method

The neighborhood solution structure of the TS method has three common modes introduced in section 3: (1) swap move, (2) insert move, (3) insert and swap move. In this research, the objective value of the resource allocation is the priority of each activity of the project utilizing resources, which is a sequential array problem. The previous research presented that, for the array problem, the efficiency of the swap move was better than that of the insert move [5] But, during research, it was found that the move by using the swap move is less if the scale of the project is large, however, an insert move is created by two swap moves and the move of the insert move is greater than that of the swap move. Thus, this research utilizes such two modes as the swap move and the insert move for the neighborhood solution structure of the resource scheduling problem, and the two moves are compared when making a sensitivity analysis.

Memory Structure of Tabu list for the RCPSP based on the TS method

The memory structure of Tabu list is mainly used to memorize the several precedent moves, that is, to memorize the several precedent moving paths, which is divided into longer term memory and short term memory. At present, the simple TS method with the short term memory is usually applied, and there is additional related research. Thus, this research utilizes the memory list with the short term memory. The tabu list is mainly applied to memorize the precedent moves, and thus the memory structure of Tabu list depends on the structure of the neighborhood solution.

Termination criterion of RCPSP based on TS algorithm

The stopping rule of the TS method is flexible. If satisfying the condition that searching objective is a criterion, the algorithm will set the stopping rule as the following two conditions, either one of the following these two conditions is satisfied and then stop calculating.

(1) Maximum number of computation for constraints.
(2) Maximum number of computation on the condition of not finding better objective value.

Cases Experiment

In this section, through positive case study, the analysis and computation model established in this research will be verified. It will be mainly divided into two parts for discussion, which are the performance analysis and sensitivity analysis of the RCPSP model using TS algorithm.

Performance Analysis

This research makes a performance comparison on the 110 optimal solution cases concerned with the resource scheduling and leveling problems presented by Patterson[1] via using the scheduling method proposed by Lin in 1995[5]. Its purpose is to achieve the objective of the shortest time limit on the condition of constrained resources. Considering the 110 experimental scheduling cases presented by Patterson, this research makes a performance comparison by using this research's algorithm and those of previous related studies. The solution error rate and optimal solution quality are also compared respectively, in which the average error rate computation mode refers to equation 4.

$$\text{Average error rate} = \frac{\text{(Feasible solution of a case i – Patterson's optimal solution of case i)}}{\text{Patterson's optimal solution of case i}} * 100\%$$

(Equation 4)

Its purpose is to find the solution quality of algorithms in this research and other related studies. This research is verified and compared with related studies by using the optimal solution case presented by Patterson, shown in Table 1, where the solution error rate is 0.187. Compared with the previous related studies, the optimal solution quantity obtained using the TS method in this research is remarkably more than that of related studies. Its solution quality is also obviously improved, verifying that this research has better solution performance.

This research's superior rate compared with previous related studies is above 4.7%, shown in Table 2. It shows that this research is better than previous studies when solving the 110 optimal solution cases on resource scheduling and leveling as presented by Patterson[3]. This superior rate is achieved by taking this research's average error rate as the basis and individually comparing it with each related study, shown in Table 2.

The verified results show that the solution objective value in this research is better than that of previous studies, while the solution of each stage in this research is compared with that of previous studies.

Conclusions and Suggestions

In this section, based on the results of this study, its contribution and conclusions, and suggestions are presented for future research.

1. TS method has already been applied in different fields to solve combinatorial optimization problems and achieve obvious outcomes. However, there are few related applications on construction engineering using the TS method. Therefore, in this research, a model suitable for solving the resource scheduling problems of construction engineering projects is established by using the TS method. The results prove that the algorithm presented by the paper can be applied in solving the multi-resource scheduling optimization problem and obtain optimal solution or near optimal solution.
2. Compared with the other traditional computation models (such as: mathematical model, traditional heuristic model, AI (GA, SA) based computational model, etc) to solve the RCPSP, some complicated procedures and heuristic rules are used to determine the resource priority allocation sequence. Thus, although the results obtained in this research using the TS algorithm are not guaranteed to be the optimal solutions, the steps for searching solutions can be remarkably reduced. Also, based on the result of performance test with the other model. The model presented by the paper provides a better solution quality than that of the other related algorithm in the Patterson's 110 cases. More than that, the unnecessary computation procedures are also simplified to effectively achieve the optimal solution or near optimal solution in the model proposed by the research.

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$$\text{Average error rate} = \frac{\text{Feasible solution of a case i} - \text{Patterson's optimal solution of case i}}{\text{Patterson's optimal solution of case i}} * 100\% \quad \ldots \text{(equation 4)}$$

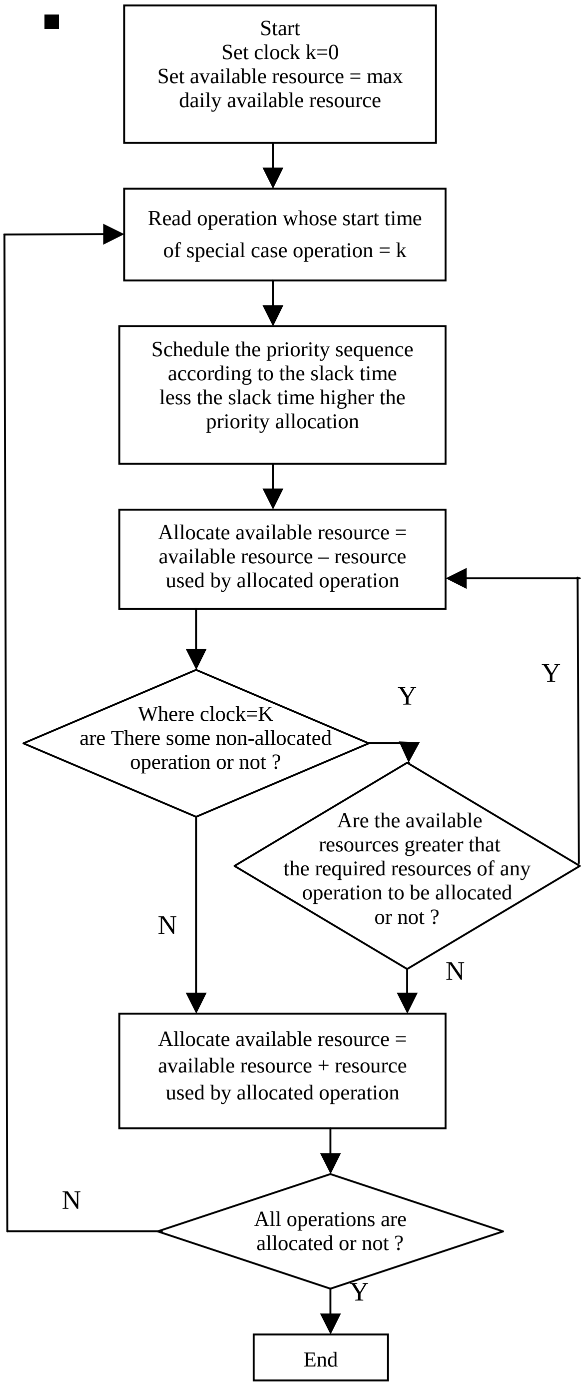

Figure 1 Flow chart of solving the starting solution by the MINSLK method

Table 1 Comparison on computation results and related studies for 110 optimal solution cases

Related studies			
Bell&Han	Lin	Yang	This research
Amount of gaining optimal solution			
41	75	79	102
Average error rate			
2.287	1.086	0.883	0.187

Table 2 Comparison on better solution rate and related studies for 110 optimal solution cases unit: %

Related studies			
Bell&Han	Lin	Yang	This research
Average error rate			
2.287	1.086	0.883	0.187
Superior rate of this research			
12.23	5.807	4.722	