Prefabricated House Precast Part Project Scheduling Optimization Problem Based on Network Planning

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Abstract: Project scheduling has been the core of project management, whose largest characteristics are the limitation of resources and the diversity of activity modes. And the prefabricated building has become the most potential building form due to the promotion of policies and its own unique advantages. However, the unreasonable project scheduling might cause some problems, such as resource waste problem. This study established the mathematical model for multi-mode resource constrained project scheduling problem on Prefabricated house precast parts project, which realized the comprehensive optimization of time and cost under the condition of satisfying the constraints of logical relation and resource. And then the problem was solved by Cplex in Python, the optimized scheduling scheme was also obtained. It might provide reliable basis for project management.

1. Introduction

Unreasonable project scheduling has become the crucial factor to the time delay and budget overspending. Prefabricated building has become a building form vigorously promoted by the government due to its characteristics of green and low carbon. And some areas introduced the policies for subsidies and preferential, such as Beijing, Shanghai. Prefabricated buildings are developing towards the trend of large-scale, complex and individualized, which puts forward higher requirements for project scheduling. Thus, it is of importance to optimize the project scheduling. And the resources are generally constrained and the activities usually covers various alternative modes in the process of construction, the MRCPSP (multi-mode resource constrained project scheduling problem) is near to the engineering state.

MRCPSP was first proposed in 1977[1]. In 1982, Talbot creatively proposed the mathematical model of MRCPSP[2] that realized the objective of minimizing time under the condition of satisfying the constraints of logical relation and resource (renewable resources and non-renewable resources) when each activity only can select one mode. Recent years, some scholars optimized the construction project scheduling through the improved model, such as Liu jia[3]and Wu hao[4]. This study researches the MRCPSP with the objective of the comprehensive optimization of project time and cost, because the project quality is a qualitative indicator, which is hard to quantify. MRCPSP belongs to NP-hard problem[5], which is difficult to find a solution suitable for all cases. Liu Shengming & Feng Shuxing[6] and ChangChun etc[7] all solved the MRCPSP by the Cplex. Therefore, this study resolved the MRCPSP of prefabricated house precast parts by the Cplex.
2. Problem description and model construction

The MRCPSP of prefabricated house precast parts takes the comprehensive optimization of project time and cost as the objective, and the constraint conditions are logical relation constraint and resource constraint. In this study, the MRCPSP and the parameters used are described, and then the mathematical model is constructed.

2.1. Problem description

The MRCPSP of prefabricated house precast parts might be described as: The project contains several activities, of which the first and last two are virtual activities, which mark the beginning and end of the project. Each activity has multiple alternative execution modes, and each mode represents a specific set of time, resource and cost. And then the number of execution mode selected by each activity is fixed and equal; each activity can only select one mode and the mode selected can not change. Each activity and its logical relationships are represented by AON (Activity on node). The activities are subject to two constraints:

Logical relation constraints. The amount of activity in the project is limited. Each activity is not allowed to break during the execution once it started, and the sequential relationship between the activities is “start-end”.

Resource constraints. Resource constraints are divided into renewable resource constraint and non-renewable resource constraint. Renewable resources are the resources that has a limited supply during each unit period of the project and will be replenished in the next unit period. For the renewable resource constraints, they are required that the resource consumption of the executing activity should not be larger than the supply in a unit period. Non-renewable resources are a kind resource that is limited and constantly consumed during the whole project. The non-renewable resource constraints require that the resource consumption of all activities not be more than their supply throughout the project.

2.2. Model construction

2.2.1. Parameter definition

In order to better express the mathematical model of MRCPSP, the parameters involved in the model are defined and described, as shown in the following table:

| Parameters | Definition | Description |
|------------|------------|-------------|
| j          | Index of activities | j=0,1,2,3,...,J,J+1 |
| i          | Index of precedent Activity for j |
| P_j        | The set of Index of precedent Activity for j |
| t          | Index of time |
| m          | Index of modes | m=1,2,...,M_j |

| Parameters | Definition | Description |
|------------|------------|-------------|
| c_{jm}     | The cost of activity j performed in mode m |
| f          | Index of renewable resources | f=1,2,3,...,F |
| k          | Index of non-renewable resources | k=1,2,3,...,K |
| R_f        | Capacity of renewable resource f |
| N_k        | Capacity of non-renewable source k | The supply is fixed |

The supply is fixed.
### Parameter definition

The mathematical model of MRCPSSP for prefabricated house precast parts is divided into two parts: objective function and constraint condition:

#### Analysis of objective function

The mathematical model is designed to minimize the project time and cost. The time of the project is represented by the completion time of the last activity (activity J+1), and the project cost is represented by the sum of the costs of the execution modes selected by all activities. And then the different weights are given to project time and cost indicate different preferences of project managers. The mathematical expression is as follows:

\[
\text{Min} \left( \omega_T * \sum_{m=1}^{M_j} \sum_{t=EF_i}^{LF_i} t * x_{jm} + \omega_C * \sum_{j=1}^{J} c_{jm} \sum_{m=1}^{M_j} \sum_{t=EF_i}^{LF_i} x_{jm} \right)
\]

#### Analysis of constraints

Constraint conditions are divided into logical relation constraints and resource constraints. Logical relation constraint is that activity j starts to execute only if all the activities in the set of precedent activity (Pj) for j has been completed. The mathematical expression is as follows:

\[
\sum_{m=1}^{M_j} \sum_{t=EF_i}^{LF_i} t * x_{jm} \leq \sum_{m=1}^{M_j} \sum_{t=EF_i}^{LF_i} t * x_{jm} - d_{jm}, i \in P_j
\]

\[
\sum_{m=1}^{M_j} \sum_{t=EF_i}^{LF_i} x_{jm} = 1, j = 1, 2, 3, \ldots, J
\]

\[
x_{jm} \in \{0, 1\}
\]

For renewable resource constraints and non-renewable resource constraints, the mathematical expression is as follows:

\[
\sum_{j=1}^{J} n_{jm} * \sum_{t=EF_i}^{LF_i} \sum_{m=1}^{M_j} x_{jm} \leq N_{k}, k = 1, 2, 3, \ldots, K
\]

\[
\sum_{j=1}^{J} f_{jm} * \sum_{q-t+1 \leq d_{jm}} \sum_{m=1}^{M_j} x_{jq} \leq R_{f}, f = 1, 2, 3, \ldots, F
\]

\[
\sum_{m=1}^{M_j} \sum_{t=EF_i}^{LF_i} x_{jm} = 1, j = 1, 2, 3, \ldots, J
\]

\[
x_{jq} \in \{0, 1\}
\]
Where, the q is a unit period between the start time (t+1-djm) and the finish time (t) for activity j.

3. Model solution based on Cplex

As a tool to solve optimization problems, Cplex can deal with thousands of variables and constraints and obtain the exact solution. And, the algorithm of Cplex can be invoked from other programming languages to solve problems. In this study, the MRCPSP of the prefabricated house precast parts is solved by using the Cplex in Python, and the optimal scheduling scheme satisfying the constraints is obtained.

3.1. Project overview

The prefabricated house outer wall panel production project includes 18 activities, from the mold figure drawing, reinforcement processing and binding to mould dismantling, surface treatment and acceptance warehousing. And each activity has three execution modes: rush mode, normal mode and slow mode. And then each activity needs four kinds of renewable resources (R1, R2, R3, R4) and four kinds of non-renewable resources (N1, N2, N3, N4), among which R1 is the reinforcement worker, R2 is the concrete worker, R3 is the mold worker, R4 is the polystyrene board worker; N1 is the material needed to make the polystyrene board, N2 is the reinforcement, N3 is the concrete, and N4 is the material needed to make the mold. The daily supply of each renewable resource is 18, 18, 14 and 18 respectively, and the daily supply of each non-renewable resource is 30, 250, 240 and 150, respectively, during the whole project. The project pays more attention to the project time, and the weight of the project time is 0.8 and the weight of the project cost is 0.2. According to the logical relationship between each activity, the AON of the project is shown in the following figure:

![Figure 1. The AON of the project](image)

According to the relevant information of resources and costs corresponding to various execution modes of each activity in the prefabricated house outer wall panel production project, the MMRCPS of the project is resolved by Cplex in Python. And, the construction period and cost are greatly different in units and magnitude, the normalization method is adopted to make them comparable. The optimized scheduling scheme and the selected execution mode of each activity are shown in the table 2:

| Index of activities | The name of activities       | Mode | Duration of activity | Discrete time point |
|---------------------|-------------------------------|------|----------------------|---------------------|
| 0                   | start                         | 1    | 0                    | 4 8 12 16 20 24 28 32 |
| 1                   | Mold figure drawing           | 1    | 2                    |                     |
| 2                   | Reinforcement processing and binding | 3    | 5                    |         |
4. Conclusion

In the optimized project scheduling scheme obtained in Table 2, 15 activities choose the rush mode (except the first and last activity), indicating that the resource supply of this project was relatively sufficient, which provided convenience for compressing the project time. For some projects with very tight schedule requirements, actively innovate the rush mode and explore alternative new technologies and new materials, so as to reduce the increase of resources and costs while reducing the project time.
The consumption of the four renewable resources at any moment is shown in the figure 2. Compared with the other three types of workers, reinforcement workers are more fully utilized. The other three types of workers have not been utilized for a long time, resulting a very serious phenomenon of workers' downtime. The managers of this project should take active measures to dispatch idle workers to other positions to effectively avoid the waste of resources.

In this study, the optimal scheduling scheme is obtained by studying the multi-mode resource constrained scheduling problem of prefabricated house outer wall panel production project, and effective measures are taken to ensure the full utilization of resources, which can help project managers to make scientific decisions.

References
[1] Elmaghraby S E. (1977) Activity networks: project planning and control by network models. Wiley.
[2] Talbot F B. (1982) Resource-constrained project scheduling with time-resource tradeoffs: the non-preemptive case. J. Management Science., 28(10): 1197-1210.
[3] Liu J. (2018) Research on construction project scheduling optimization problem based on network planning. Beijing: Beijing jiaotong university.
[4] Wu H. (2016) Research on the scheduling of the uncertain prefabricated housing project for the uncertain period. Xi’an: Xi’an University of Architecture and Technology.
[5] Blazewicz J, Lenstra J K, Kan A R. (1983) Scheduling subject to resource constraints: classification and complexity. J. Discrete Applied Mathematics., 5: 11-24.
[6] Liu S.M, F S.X. (2017) Disruption Management Simulation for Multi-mode Resource-constrained Project Scheduling Problem J. Journal of System Simulation., 29(3): 662-668.
[7] Changchun L, Xi X, Canrong Z, et al. (2018) A column generation based distributed scheduling algorithm for multi-mode resource constrained project scheduling problem. J. Computer & Industrial Engineering., 14: 258-278.