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# Integrated scheduling and batch ordering for construction project

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ABSTRACT

Multi-Mode Resource Constrained Project Scheduling Problem and material batch ordering for construction project are integrated to help project manager consider various trade-offs among several costs, such as renewable resources' cost, material price, ordering cost, back-ordering cost, inventory holding cost and reward/penalty for early/late project completion. Therefore, we prove a mixed integer programming model and impel to calculate inventory holding cost and back order cost in objective function. Moreover, a hybrid algorithm combined adapted harmony search and genetic algorithm is proposed correspondingly. In order to inherit elitist solution and maintain population's diversity simultaneously, we add a selection operator when the harmony memory is initialized and modify the replacement operator based on distance. Besides, genetic algorithm is adopted based on a '012' coding scheme. Finally, algorithm and model performance is presented and several project instances are provided with different network structures and realizations to discuss the factors on total cost.



## 1. Introduction

The paper deals with combined problem of construction project scheduling and material batch ordering. The traditional method is generally to treat project scheduling and material ordering separately, i.e., project scheduling is executed firstly, and then a material ordering plan is determined taking the activity schedule as an input. However, from the perspective of project integration management, the traditional method makes the project manager not consider various trade-offs among several costs. These costs maybe include renewable resources' cost, material cost, ordering cost, back-ordering cost, holding cost of material, a reward (penalty) for early (late) project completion etc. In practice, the resource conflicts exist among these costs, for example, less penalty or more reward implies longer duration, which could lead to increase the input of renewable resources and materials such that results in a series of cost modifications related to ordering. Therefore, such cost trade-offs indicate that project scheduling and material ordering are inseparable and must be treated simultaneously in an integrated manner to coordinate project time, cost and procurement management.

Aquilano and Smith in 1980 [1] introduced the integrated problem for the first time when a hybrid model combining the critical path method with material requirement planning was developed. Subsequent to it, Smith-Daniels and Aquilano [2] presented an improvement and a scheduling heuristic for large project based on the least slack rule, with regard to renewable and nonrenewable resources, in consideration of variations in activity duration and precedence constraints. Smith-Daniels and Smith-Daniels [3] discovered that the latest starting time schedule provides an optimal solution to the problem with fixed activity duration. They also showed that the problem could be solved optimally while it is decomposed into a derivation of the project schedule and a derivation of the ordering plan. In the above research, the objective is just to

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optimize the total costs of material ordering, inventory holding, completed activities holding and project delayed; moreover, it is assumed that the activity duration is constant, i.e., there is no alternative.

Dodin and Eliman [4] extended the problem by introducing activity crashing, rewards for early completion as well as materials quantity discounts. It is showed that the variable duration caused by crashing gives more flexibility to project scheduling, resulting in more cost reduction and allowing for savings on the completed activities and materials holding cost. However, their experiment showed that the network structure and size highly influenced the computation time.

Schmitt and Faaland [5] proposed a heuristic algorithm for scheduling a recurrent construction to maximize the net present value of cash flows. It constructs an initial schedule that dispatches worker teams to tasks for the backlogged products and optimizes a series of maximal closure problems to find material release times.

Accordingly, Sajadieh et al. [6] developed a genetic algorithm based on the model to solve the large scale problem. However, in the model, the crashing cost for an activity is a constant, i.e., all factors lead to the same impact on an activity; moreover, renewable resources which mainly determine the project schedules are not considered; furthermore, amount of material required which is assumed to be independent of the activity duration is impractical, because the increase in resource investment may result in the reduction of duration, and vice versa; in addition, material shortage is not permitted.

In order to make the problem in construction more realistic, Multi-Mode Resource Constrained Project Scheduling Problem (MRCPSP) is introduced on one hand [7–10]. It is an extension of Resource Constrained Project Scheduling Problem (RCPSP). In this problem, each activity is allowed to have multiple modes, one of which should be executed to determine activity duration and renewable and non-renewable resource requirements; moreover, the activity duration is unique for each resource allocation. That is because that, not only the quantity of certain resource, but also different resource collocation is likely to impact activity duration, i.e., we could shorten duration by increasing a sort of input or employing other alternative due to substitution effect. Hence, the crashing cost could be generalized to vary because of different causes, and be obtained according to the amount of requisite resources and their unit costs as well.

On the other hand, batch ordering addressed in this paper is widely applied in construction, especially large project [11–14]. As the name implies, any order must be an integer multiple of a given quantity; furthermore, backorders are allowed to make up for quantity discrepancies which result from batch ordering. Besides, inventory holding cost and ordering cost exist as well, but completed activities holding cost could be ignored, since the activity completed is generally a part of the final construction.

Overall, in the process of project scheduling, mode selection determines the demand for renewable resources and materials, which correspond to activity duration as well. Thus, order size could be recognized which adhere to the requirement at present. Thus, a schedule could be identified which is composed of available resource requirements and durations of all the activities; meantime, an ordering plan which consists of order timing and order size could be achieved as well. This shows that project scheduling and material ordering is actually performed simultaneously. Consequently, MRCPSP and batch ordering are integrated and conducted to search a balance.

In the next section, we will define the notation and represent the formulation. We will discuss how to compute inventory holding cost and back ordering cost in Section 2, and describe the hybrid algorithm in Section 3. Numerical experiment will be conducted in Section 4. Finally, conclusions and future research will be presented.

## 2. Mathematical formulation

We consider scheduling and material batch ordering as a whole for construction project which is represented by activity-on-node network. The precedence relations of activities are finish-start with zero time lags; moreover, it is assumed that material consumption is coasting at a uniform speed, and material replenishment is instantaneous; besides, backorders just issue from quantity discrepancies by batch ordering as previously mentioned.

### 2.1. Notations

Before presenting the mathematical formulation, we define notations used in the formulation.

#### 2.1.1. Indexes

$i$ index of activities, $i \in \{0, 1, ..., N+1\}$,where 0 and $N+1$ indicates dummy source and dummy sink activity respectively.
$m$ index of activity modes, if $i \in \{1, 2, ..., N\}$ then $m \in \{1, 2, ..., M\}$; otherwise $m = 1$.
$k$ index of type of renewable resources, $k \in \{1, 2, ..., K\}$.
$l$ index of type of materials, $l \in \{1, 2, ..., L\}$.
$t$ time index, $t = 0, 1, 2, \ldots$.

#### 2.1.2. Parameters related to scheduling

$P_i$ set of immediate predecessors of activity $i$.
$d_{im}$ duration of activity $i$ executed in mode $m$.
$r_{imk}$ amount required of renewable resource type $k$ to process activity $i$ in mode $m$ per-period.