# The Model for Multi-Mode Resource-Constrained Multi-Project Scheduling Problems

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The multi-mode resource-constrained multi-project scheduling problems (MMRCMPSPs) considering supply management and sustainable approach in the construction industry under uncertain conditions have been investigated using evidence theory to mathematical modeling and solving by multi-objective optimization algorithms.

multi-mode resource-constrained multi-project scheduling problems (MMRCMPSPs)

multi-objective mathematical modeling | metaheuristic optimization algorithms | uncertainty

evidence theory | sustainability | integration | construction | industry | management

## 1. Introduction

Proper management and planning in resource-constrained project scheduling problems (RCPSPs) is one of the most current and complex issues in the field of project management, which aims to minimize the duration of the project. In recent years, considerable effort has been devoted by researchers to this area. It is worth mentioning that attention to the RCPSP concept is essential and used in various industry domains, such as the construction industry [1].

One of the special cases in this field is multi-mode resource-constrained project scheduling problems (MMRCPSPs), which can be extended to a multi-project with significant application and importance for real-world implementation issues. Scheduling of various projects and the division of various resources can be performed with two approaches: single-project and multi-project. In the single-project approach, projects are artificially integrated through virtual start and end activities and become a single project. It should be noted that both approaches can produce different schedules with the same priority rules [2]. Given that the multi-project situation is often more common in practice, it probably provides a better opportunity for further progress. In large and modern companies and organizations, multi-project scheduling is a crucial issue. Many projects are set up and implemented in these organizations, requiring simultaneous scheduling [1]. The multi-project scheduling problem was first studied by Pritsker et al. [3], who presented a practical model for multi-project scheduling and formulated the model as an example. However, no solution method for multi-project scheduling problems has been presented in their research.

Over time, the multi-project scheduling problem has attracted more researchers' attention, and various methods and procedures have been presented to solve it. Also, the integration of project scheduling and material ordering in the last three decades has been given more attention to ensure the project's profitability. The essential concern about ordering materials in the timing of various projects is to choose the right projects and suppliers so that the completion costs are minimized and, ultimately, the profitability of the projects is maximized [4]. In recent years, in addition to increasing profits, paying attention to sustainable development, sustainability dimensions, and adopting sustainability in the construction industry is felt as a necessity. Sustainability is a multifaceted concept that refers to economic, social, and environmental values and is a challenge in properly managing construction industry projects [5][6]. The integration of new issues in project scheduling and various sustainability aspects is currently for managers' attention. In fact, the desire to develop and use new management methods for project scheduling and management has increased, and the foundations of sustainability have become dominant in various fields of fundamental management in organizations and businesses [6].

Based on the mentioned points, an integrated time–cost optimization model is presented for multi-project scheduling and resource ordering in construction industry projects with a sustainable approach under uncertain conditions. In this respect, a multi-objective mathematical model has been proposed for the investigated problem, and then metaheuristic algorithms have been used to solve the model. The problem of the current research includes multi-projects, and multi-mode implementation has been considered for the activities of each project, and each activity will be completed in only one mode. Also, the types of project resources are renewable and non-renewable.

It is worth mentioning that some previous studies have dealt with the multi-project scheduling problem with a simple and discrete approach, and a number of them have also considered various items often separately, such as material ordering, supplier selection, or sustainability aspects [7][8]. However, most of these studies have not paid adequate attention to an integrated approach in the field of multi-project scheduling and consideration of resource constraints, uncertainty, suppliers, sustainability, and other complementary aspects, such as interest rate, discount factors, risk criteria, organizational criteria, and competitive criteria. Considering that the mentioned cases significantly affect the optimal scheduling of construction projects, their consideration and inclusion in multi-project modeling in the construction industry can lead to the appropriate and more favorable implementation of the projects.

In this regard, the proposed model in this research has been designed and developed according to the shortcomings of previous research models for multi-mode resource-constrained multi-project scheduling problems (MMRCMPSPs). It has been tried that the presented model has an integrated and complementary method along with the scheduling of project activities simultaneously with the approach of sustainable development in the construction industry, influential and various issues such as the optimal use of renewable and non-renewable resources and sustainability aspects are also addressed. As mentioned earlier, in the problem being investigated, uncertainty has also been taken into account, where the parameter of the processing time of activities is non-deterministic. It is worth noting that although many methods, such as probability theory, fuzzy, entropy, and evidence theory, have been proposed to deal with uncertainty, evidence theory has the advantage of dealing with

uncertainty flexibly and logically based on evidence and knowledge and has wider applications in measuring uncertainty in decisions [9]. Therefore, regarding this matter, evidence theory has been used in the current research to face the uncertainty of the time of activities, and a new functional investigation has been carried out.

Actually, in this research, a novel multi-objective mathematical model and relations with a new integration methodology for multi-mode resource-constrained multi-project scheduling have been presented by considering many different cases, such as costs, times, risks, profits, sustainability, uncertainty, suppliers, carbon penalties, interest rates, environmental, technical, social, organizational, and competitive factors. Indeed, this integration and optimization between various items, also stated in the different parts of the research, is the distinguishing feature of this work from other studies in this field and one of the contributions. Furthermore, solving and investigating the proposed model using metaheuristic optimization algorithms and uncertainty theories, such as evidence theory, is one of the strengths of this research.

## 2. The Model for Multi-Mode Resource-Constrained Multi-Project Scheduling Problems

The problems of project scheduling have attracted the attention of many researchers in the past years, and many studies have been conducted in this field and in different situations, some of which have been briefly reviewed and explained in the following section. In this regard, Le [10] studied resource-constrained multi-project scheduling problems (RCMPSPs) by considering the moving time of renewable resources (labor, machinery, and equipment) in Vietnam's construction projects. This research examined several projects in different places and at large distances from each other. In the presented model of this research, allocating a resource from one project to another was considered very expensive and time-consuming. Also, an algorithm based on priority rules was presented to solve this problem and minimize project implementation time. Tseng [11] also presented two heuristic algorithms to solve the multi-project scheduling problem with resource-constrained in multi-mode. The first algorithm is a parallel scheduling algorithm, which is a combination of priority rules for activities and modes, and the second algorithm is based on the genetic algorithm (GA). Browning and Yassine [12] studied the static RCMPSP with two objectives for minimizing project delays and portfolio lateness and presented a mathematical model for the investigated problem. Zhang and Sun [13] also investigated the multi-project scheduling problem with limited resources and solved this problem using priority rules based on heuristics methods.

Liu and Chen [14] studied the multi-project scheduling problem in the construction industry, assuming the allocation of different resources. They discussed the resource allocation mechanism for multi-project scheduling problems and then presented an optimization-based model to solve resource allocation problems. This research designed a scheduling model with constraints and different optimization objectives, including minimizing total costs and project duration, according to each activity's combination of resource allocation. Singh [15] investigated the multi-project scheduling problem by considering resource constraints using rule-based priority and analytic hierarchy process (AHP) methods. Suresh et al. [16] also studied the multi-project scheduling problem with limited resources and the assumption of transfer times of resources between activities. Their study presents a new approach based on the genetic algorithm to solve the multi-project scheduling problem with resource transfer times, where the net present

value (NPV) of all projects is maximized concerning renewable resource constraints. El-Abbasy et al. [17] studied multi-objective optimization for multi-project scheduling in the construction industry using the elitist non-dominated sorting genetic algorithm. They presented the development of an automated system that optimizes the scheduling of several construction projects according to different objectives, considering financial aspects and required resources under the operating system. Pinha et al. [18] have also addressed the multi-project scheduling problem with limited resources in their research. In this study, they presented mathematical modeling for multi-project scheduling with multiple resource constraints in ship repair.

Joo and Chua [19] have addressed the MMRCMPSP assuming splitting of ad hoc activities in civil engineering companies. They presented a mathematical model for this problem and used a simulated annealing (SA) algorithm to solve it. Rostami et al. [20] have also investigated multi-project scheduling problems by assuming resource pool locations for periodic services. They considered the transfer of resources between projects and presented a mathematical model to minimize the completion time. Further, they used the artificial bee colony algorithm to solve the model. Li and Xu [21] studied the multi-project scheduling problem with resource constraints using a multi-agent system and a two-stage decomposition method. Nabipoor Afruzi et al. [1] also presented a robust optimization mathematical model for the multi-project scheduling problem with limited resources under conditions of uncertainty in the time of activities. Shafahi and Haghani [22] addressed the problem of project scheduling and selection of projects with phase interdependence between phases. They presented a mixed integer programming (MIP) mathematical model that maximizes the NPV and future investments under time limitations on budgets and reinvestment strategies. Birjandi and Mousavi [23] presented fuzzy mixed integer nonlinear programming (MINLP) in a mathematical model for the RCPSP in fuzzy conditions with multiple routes. To solve the model, they used a hybrid metaheuristic approach based on particle swarm optimization (PSO) and genetic algorithms to minimize project completion costs. Additionally, Garcia-Nieves et al. [24] proposed a multi-objective linear-programming optimization model for scheduling repetitive activities in construction projects. Their research presented a guide and computational testing of a new mathematical model that can optimize construction schedules according to the most given conditions in terms of time and location.

Zou and Zhang [25] presented a constraint programming approach with atypical activities for scheduling repetitive projects by soft logic. They have developed a flexible, iterative scheduling model by integrating soft logic into the time-cost trade-off. This model allows similar activities in different units to be performed in parallel (run simultaneously), sequentially (one after the other), or partially parallel and partially sequentially. Also, Rahman et al. [26] addressed the problem of a construction project scheduling with resource-constrained using a memetic algorithm. Zhang and Cui [27] investigated the problems of project scheduling and ordering materials considering the storage space limitation. They presented a two-objective mathematical model for minimizing the construction project's time and related costs, including material inventory costs, ordering costs, and indirect costs. The proposed model is NP-HARD, and the NSGA-II algorithm has been used to solve it.

Also, in recent years, many studies have been performed on project scheduling problems, considering the aspects of sustainability. El-Alfy [28] investigated the design of sustainable constructions according to value engineering principles. Also, Hwang et al. [29] have addressed the management of green and sustainable construction projects

to improve project scheduling performance. Ali et al. [30] also reviewed and studied the project management and sustainability literature. They examined previous research on the impacts of sustainability aspects in different phases of project management. Their investigations showed that the components of sustainability significantly affect all stages of project management, and their consideration leads to improvements in the project management process. Mahmoudi et al. [31] investigated the problem of sustainable project scheduling in construction and presented a mathematical model. The purpose of the mathematical model proposed by them is based on the aspects of sustainability. It includes minimizing the costs of pollutants and job injuries, for which they used the SA algorithm for optimization. Their study considers the project network dynamically, and the model's parameters are also probabilistic.

Wang et al. [32] studied the issue of green project planning concerning sustainable development. For this problem, they presented a two-objective mathematical model with the goals of minimizing the project cost and maximizing the reduction of pollutant gas emissions. They used the NSGA-II to solve the model. Several construction projects are considered in the investigated problem, and the presented mathematical model deals with the scheduling of project activities in the planning period with sustainability goals. Habibi et al. [7] have also investigated the problem of scheduling project activities and ordering materials, taking into account sustainability considerations for construction projects. Mahmoudi et al. [33] evaluated, selected, and scheduled urban road construction projects (URCP) considering sustainability. The network for a data envelopment analysis (DEA) model is first built. Then, considering the elements of sustainability, combining data coverage analysis, game theory, and the selection and scheduling of sustainable URCP, a two-level model for the selection and scheduling of URCP is presented. Finally, an algorithm is proposed to solve the model.

Khayamim et al. [34] presented a sustainable approach for selecting and scheduling urban transportation infrastructure projects in large networks. In their research, a new procedure has been presented to accomplish the selection and scheduling of urban transportation projects simultaneously. They also presented a mathematical programming model, and according to the relevant model, a two-phase hybrid solution method was developed. Askarifard et al. [35] have also provided a robust multi-objective optimization model for project scheduling by considering risk and sustainable development criteria. They presented a model with the objectives of minimizing cost, risk, and socio-environmental impacts to reduce project delays. RezaHoseini et al. [8] have also presented a bi-objective model for green construction supply chains under conditions of uncertainty, in which supplier integration and multi-project scheduling are considered. This study evaluates the construction supply chain using a bi-objective linear mathematical model in which the actual environmental impacts of vehicles in terms of distance, pollution status, and road slope are considered. Also, the synergy between supplier selection and project timing in the proposed green supply chain is considered in this research.

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