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Recent Advancements and Methods for Solving Resource-Constrained Multi-Project Scheduling Problems: A Review

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Abstract

The resource-constrained multi-project scheduling problem (RCMPSP) presents substantial challenges in project management, especially in industries where multiple projects compete for limited resources. This study provides a comprehensive review of advancements in mathematical models, methods and strategies used to address the complexities of RCMPSP. This review explores the applications of RCMPSP solutions in various fields, including construction, manufacturing, and healthcare, and identifies key research gaps. By examining recent studies, the review categorizes solution techniques into exact methods, heuristics, metaheuristics, and hybrid methods. Each method is evaluated for its efficacy in improving scheduling efficiency and managing project complexity under resource constraints. In particular, hybrid approaches, which combine various techniques, have shown promise in balancing computational feasibility with solution quality, making them suitable for large-scale industrial applications. The review concludes by identifying key areas for future research in RCMPSP, emphasizing the need for models that integrate sustainability and real-time adaptability to meet project demands along with different solution methods.

Keywords
Multi-Project Scheduling, Resource Allocation, Metaheuristic Optimization, Multi-Objective Optimization, Genetic Algorithms.

1. Introduction
The scheduling of projects within available resources is a key component of project management practice, particularly in areas where resources are limited and there is a need to manage several projects at once (Sánchez et al. 2022). They define the resource-constrained multi-project scheduling problem (RCMPSP) as that entails the process of allocating start times to the tasks associated with two or more projects that have to be carried out concurrently while ensuring all internal task relationships are satisfied and resources are constraints. The allocation of resources, the arrangement of activities, and the achievement of project completion on time are critical for the success of the project and efficient management of resources. The resources used in projects can be categorized as renewable, non-renewable, or partially renewable (Sánchez et al. 2022). Renewable resources are consistently restored at the beginning of each period, allowing for repeated usage within the project, such as labor hours, machineries, equipment (Asadujjaman et al. 2021a; Asadujjaman et al. 2022). Non-renewable resources, on the other hand, are finite within the entire project timeframe; once allocated, they cannot be replenished, making careful allocation essential (Asadujjaman et al. 2021b). An example is a fixed budget allocated for the project's duration, which, once used, cannot be restored. This type often requires consideration of multiple execution modes, as varying tasks may use resources at different rates. Lastly, partially renewable resources are replenished periodically within the project duration. The management of resource allocation over several projects at the same time presents a huge challenge due to their complexities (Cristóbal et al. 2018; Zarpov 2024). In the last couple of decades, both researchers and practitioners trying to look for better and new

methods of structural multi-project management within these framework. In RCMPSP, resource management is done in two ways: either centralized or decentralized (Asadujjaman 2023). In a centralized RCMPSP, a single decision-maker manages resource allocation across projects with full visibility into each project's status. By contrast, in a decentralized RCMPSP, a central decision-maker allocates resources without detailed knowledge of individual project statuses, though they still pursue a global objective. Once resources are allocated, project managers independently schedule tasks within their assigned resources, focusing on local goals.

It is known that in multi-project scheduling with scarce resources, factors such as cost, time, and resource availability must be taken into consideration. To put it succinctly, instead of managing a single project, multi-project scheduling involves managing several projects running concurrently, without any overlap in the time frame or resources, thus presenting new challenges in project coordination to ensure effective use of available resources and the completion of projects within a portfolio. The issue of scheduling is exacerbated due to the fact that multiple projects may require the pooling of certain resources which creates a possibility of assignments conflict, resource limitation and need for trades that call for sophisticated scheduling techniques. Project planning used to be mostly done by hand or with basic algorithms that found it difficult to handle the complexities of real-world situations. Maintaining a focus on the resource exhausted project scheduling has increasingly attracted the attention of researchers and practitioners alike in the loss of weight to the project schedule management.

This has also lead to the emergence of various solution methods like exact methods, heuristics, metaheuristics and hybrid approaches. Each of these has their own advantages and disadvantages, hence reasonable for specific types of problems and applications. While various solution approaches have been proposed, there is a lack of systematic comparative studies that evaluate the efficiency, scalability, and effectiveness of these methods in diverse real-world scenarios. Besides, many studies focus on generic scheduling problems and overlook the unique challenges posed by specific industries or regions. Further, the literature on RCMPSP is fragmented, with scattered advancements across diverse domains. There is a pressing need for a comprehensive review that consolidates and synthesizes recent developments, identifies trends, and highlights future directions. Given these research gaps, there is a clear need for a comprehensive study of recent advancements and methods to solve the RCMPSP. Therefore, this literature review seeks to give a thorough summary of recent developments in project scheduling models and solution methods under resource constraints. The contributions of this study is twofold. Firstly, this paper explores RCMPSP applications in numerous industries, reviews mathematical models and advanced algorithms, and highlights emerging trends. Secondly, this paper provides a structured overview of solution methods-exact, heuristic, metaheuristic, and hybrid-emphasizing their strengths, weaknesses, and the computational efficiency of hybrid models for large-scale problems. By examining the latest research findings and methodologies, this study seeks to identify trends, challenges, and future directions in the field.

2. Methodology

2.1 Literature Search Approach

The method utilized in this study included a methodical review of literature aimed at pinpointing and examining articles released from 2005 to 2024 that discussed techniques for managing multiple projects with limited resources. Academic databases 'Google Scholar' were utilized to conduct the literature search. The search process has incorporated a few key terms, for example, "resource-constrained multi-project scheduling methods".

2.2 Criteria for Inclusion and Exclusion

In this review, we encompassed only articles that met certain inclusion criteria such as; articles published in between the years 2005 and 2024, articles that dealt with various approaches, methods or algorithms of multi-project scheduling with limited resources and the ones that provided new methods, frameworks, or designs for solving scheduling issues in multi-project. Inclusion and exclusion criteria were applied to prevent the selection of articles that were published prior to the year 2005, articles that did not concern scheduling techniques for multiple projects within resource constrains, and other irreverent and duplicated research articles. These conditions were necessary in order to ensure that only the most recent and pertinent work on multi-project scheduling was presented.

2.3 Data Extraction and Analysis

Subsequent to the identification of the relevant research work, performed data extraction in order to collect the data authors, year of publication, journal and paper titles, the methodology used and the outcomes reached/fields of application. The structured information obtained was then analyzed in order to find trends, strategies, and developments concentrating on multi-project scheduling in the resource-constrained environment.

2.4 Data Synthesis and Interpretation

The combined information was analyzed to recognize overall trends, developing approaches, and areas lacking in current research on resource-limited multi-project scheduling techniques. An examination of the findings was conducted in order to comprehend the up-to-date improvements, challenges, and future research prospects in this domain.

3. Resource-Constrained Multi-Project Scheduling Problem (RCMPSP)

Several projects P require parallel scheduling where each project $p \in P$ consists of activities $n = 1, 2, \ldots . N$ that are related according to successor-predecessor relationships ε, with start (first) and end (last) activities as dummy tasks. Each activity has a duration $D_{p,n}$. In each project p, the local resource types $LR = \{1, 2, \ldots, lr\}$ are used by the activities, whereas the global resource types $GR = \{1, 2, \ldots, gr\}$ are utilized by the activities of different projects. Each local $lr \in LR$ and global $gr \in GR$ resource type has an upper limit of $M_{p,l}$ and M_g, respectively. Each project p is defined by specific parameter values, namely start date and deadline, denoted by α_p and δ_p, start of first activity $ST_{p,1}$, arrival date α_p and completion of last activity $FT_{p,n}$, due date δ_p.

Let denote by $\phi_p(t)$ the set of activities that are currently taking place in project p at time t, and by $\phi(\mathrm{t})$ the set of currently active activities across all projects in P at time t. In this case, the mathematical model focuses on the minimization of Total makespan, TMS of classical RCMPSP (Asadujjaman et al. 2023), which is given below.

$$\text{Min } TMS = max_{p=1,\ldots,P}\left(F_{p,n}\right) - min_{p=1,\ldots,P}\left(\alpha_p\right) \tag{1}$$

Subject to:

$$FT_{p,n} \leq FT_{p,n} - D_{p,n};\ \forall(n, v) \in \varepsilon;\ \forall p \in P \tag{2}$$

$$\sum_{n \in \phi_p(t)} lr_{p,n} \leq M_{p,l};\ \forall lr \in LR; t = 1, 2, \ldots, T \tag{3}$$

$$\sum_{n \in \phi_p(t)} gr_{p,n} \leq M_g;\ \forall gr \in GR; t = 1, 2, \ldots, T \tag{4}$$

$$ST_{p,1} \geq \alpha_p;\ \forall p \in P \tag{5}$$

$$FT_{p,n} \leq \delta_p;\ \forall p \in P \tag{6}$$

Eq. 1 represent the objective function. The precedence relation among activities is expressed in Eq. 2. Resource constraints have been described in Eq. 3 along with Eq. 4, the former being a local resource constraint, and the latter a global resource constraint. Eq. 5 ensures that no project can commence earlier than its scheduled arrival time. A similar strategic constraint is suggested in Equation 6 which imposes a deadline limit.

4. Research Advancements in RCMPSP

Previous section presents the classical RCMPSP. However, the RCMPSP addresses various resource characteristics and constraints, capturing the complexities of real-world project environments. Resources can be categorized as local, specific to individual projects, or global, shared across multiple projects, which introduces challenges in managing resource conflicts and prioritization. They are further classified as renewable resources, such as manpower or machinery that replenish over time, and non-renewable resources, like budgets or raw materials, which are consumed permanently. RCMPSP can also involve activities executed in a single-mode, where tasks have fixed resource requirements and durations, or in a multi-mode, offering flexibility through alternative execution options with varying resource demands. Additionally, resource transfer accounts for the costs and logistics involved in relocating resources between projects or sites, adding another layer of complexity. These dimensions underscore the intricacy of RCMPSP and the importance of sophisticated approaches for efficient resource allocation and scheduling.

Due to its practical significance and inherent complexity, the RCMPSP has garnered extensive attention and been the subject of numerous studies over the past few decades. This is evident in Figure. 1, which presents the results of a Scopus database search using the keywords "Resource-Constrained Multi-Project Scheduling Problems." The figure highlights a substantial volume of research publications in this field, with a steadily increasing publication trend, demonstrating the sustained and growing interest among researchers.

Research Advancements in RCMPSP means the progression, innovations, and enhancements in methodologies, models, and applications aimed at improving how multi-project scheduling is conducted under limited resource availability. Apart from the traditional RCMPSP, these advancements address the inherent complexities of managing multiple interdependent projects that compete for shared resources with novel techniques and practical applications.

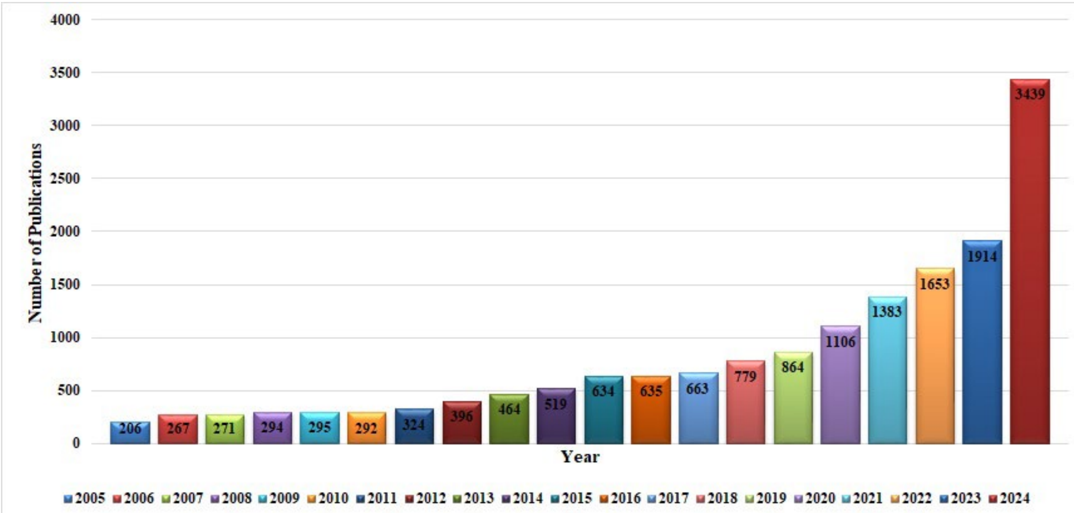

Figure 1. The number of publications on RCMPAP since 2005 (Source: Scopus)

Table 1 demonstrates significant advancements in extending traditional RCMPSP models to align with contemporary project management challenges. The integration of multi-project planning and scheduling has become essential as organizations simultaneously manage numerous interconnected projects. Research by Asadujjaman (2023) and Saif et al. (2022) highlights advanced frameworks that optimize resource allocation while considering interdependencies between tasks across multiple projects, ultimately improving operational efficiency. Another notable advancement is the development of multi-skill RCMPSP models, which reflect the dynamic nature of modern workforces where resources are not constrained to a single skillset. For instance, studies by Torba et al. (2024) and Goudarzi et al. (2023) focus on improving resource flexibility and utilization through innovative scheduling methods, enabling more adaptable and efficient project execution. The supply chain-integrated RCMPSP addresses the critical need to synchronize project schedules with the flow of materials and logistics (Asadujjaman et al. 2024).

Table 1. Extension of RCMPSP

Features	Research Work
Integrated multi-project planning and scheduling	Asadujjaman (2023), He et al. (2022), Saif et al. (2022), Rauf et al. (2020), Ahmed et al. (2021), Taghipour et al. (2020), Beşikci et al. (2015)
Multi-skill RCMPSP	Torba et al. (2024), Goudarzi et al. (2023), Haroune et al. (2023), Javanmard et al. (2022), Chen et al (2022), Chen et al (2017), Walter (2015), Heimerl and Kolisch (2010)
Supply chain integrated RCMPSP	Asadujjaman et al. (2024), Afra and Kheirkhah, (2024), Ghoroqi et al. (2023), Abdzadeh et al. (2023), Abdzadeh et al. (2022), RezaHoseini et al. (2021), Chen et al. (2018), Gholizadeh-Tayyar et al. (2018), Ghamary (2018), Tayyar et al. (2016), Liu and Zheng (2008)
RCMPSP with sustainability consideration	Goudarzi et al. (2024), Ghoroqi et al. (2023), Gholizadeh-Tayyar et al. (2021), Javanmard et al. (2022), RezaHoseini et al. (2021)

Contributions by Asadujjaman et al. (2024) and Afra & Kheirkhah (2024) propose supply chain integrated project scheduling models that reduce material delays and enhance project coordination, particularly in industries such as construction and manufacturing. Moreover, the incorporation of sustainability considerations into RCMPSP marks a paradigm shift towards environmentally responsible project management. Researchers like Goudarzi et al. (2024) and Javanmard et al. (2022) have explored frameworks that prioritize reducing energy consumption and minimizing carbon footprints, paving the way for sustainable operational practices. These extensions collectively highlight the evolution of RCMPSP to tackle increasingly complex and multidimensional project environments.

Table 2 underscores the versatility of RCMPSP models and applications across diverse industrial domains, reflecting their importance in addressing unique operational challenges. In the construction sector, RCMPSP is pivotal due to the industry's inherent complexities, such as managing overlapping tasks, resource limitations, and strict deadlines. Recent works by Mozhdehi et al. (2024) and Sayyadi et al. (2022) emphasize the optimization of resource usage and the mitigation of project delays, making these models indispensable for enhancing cost-efficiency and adherence to project timelines. In manufacturing, the focus shifts to streamlining production schedules and resource reallocation in dynamic environments.

Research by Chen et al. (2022) and Shakshi-Niaei and Sajadian (2023) highlights the development of scheduling methods that minimize production interruptions and optimize resource utilization, contributing to higher throughput and reduced downtime. Similarly, the healthcare sector leverages RCMPSP to address critical resource management challenges, such as scheduling operating rooms, allocating diagnostic equipment, and optimizing medical staff assignments. Studies by Liu (2024) and Wang et al. (2023) demonstrate the effectiveness of real-time scheduling methods in improving patient care while ensuring resource availability across facilities. Beyond these sectors, RCMPSP applications extend to areas like IT, logistics, and energy, where tailored models address challenges unique to each field. For instance, Kolisch & Meyer (2006) and Torba et al. (2024) explore RCMPSP frameworks for software development projects, focusing on managing multi-phase tasks under tight constraints. This breadth of application demonstrates the adaptability of RCMPSP in solving domain-specific problems, establishing its critical role in modern project management across industries.

Table 2. Application of RCMPSP in various field

Application field	Research work
Construction	Mozhdehi et al. (2024), Hosseinian and Baradaran (2023), Ghoroqi et al. (2023), Song et al. (2022), Sayyadi et al. (2022), Kannimuthu et al. (2020), ElFiky et al. (2020), Zhang and Chen (2018), Gholizadeh-Tayyar et al. (2016), Tayyar et al. (2016), Xu and Feng (2014), Xu and Zhang (2012)
Manufacturing	Chen et al. (2022), Cui et al. (2021), Shakhsi-Niaei and Sajadian (2021), Issa (2020), Rauf et al. (2020), Ghamary, Y. (2018), Olaitan et al. (2015), Kramarenko (2010)
Healthcare	Liu (2024), Wang et al. (2023), Sun et al. (2020), Xin et al. (2018), Hopkins et al. (2007), Kolisch and Meyer (2006)
Others	Torba et al. (2024), Kolter et al. (2024), Badur (2021), Keles (2019), Fabig and Winter (2018), Zhu et al. (2018), Chen et al. (2017), Tayyar (2017), Gholizadeh-Tayyar et al. (2015), Zhang et al. (2015)

5. Methods to Solve RCMPSP

The complexity of RCMPSP has led to the development and application of a diverse range of solution methods aimed at identifying optimal or high-quality solutions. These methods are designed to address the intricate challenges inherent in RCMPSP. The solution methods to solve the RCMPSP are classified into four types: exact, heuristic, metaheuristic and hybrid approach. Researchers have utilized exact approaches for smaller-scale problems to guarantee optimal solutions, heuristic techniques for quickly generating feasible solutions, and metaheuristic algorithms to navigate complex and large solution spaces effectively. Additionally, hybrid methods have emerged as a robust alternative, combining the strengths of multiple approaches to balance computational efficiency and solution quality. Figure 2 presents the classification of RCMPSP solving methods.

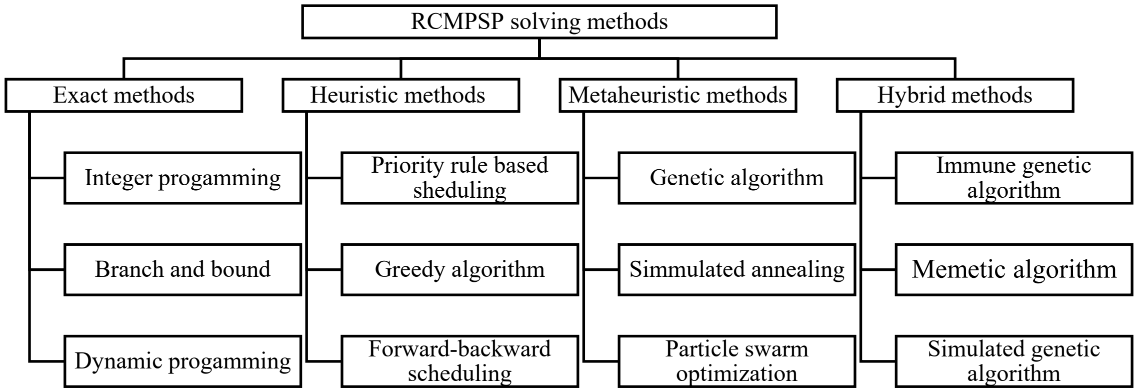

Figure 2. Classification of RCMPSP solving methods

Table 3 presents a comprehensive summary of various solution methods used to address RCMPSP and its extensions. Table 2 summarizes the exact, heuristic, metaheuristic, and hybrid approaches, each with distinct strengths and weaknesses, and applicability to different problem scales and complexities. The following paragraph discusses based on the Tables 3& 4

5.1 Exact methods

Exact methods, such as constraint programming (Hauder et al. 2020, Liu and Wang 2010), chance constrained programming (Beşikci et al. 2015), dynamic programming (Satic et al. 2022), mixed integer programming (Aghileh et al.2024, Hauder et al. 2020), branch & bound (Aghileh et al., 2024), are characterized by their ability to guarantee optimal solutions. These methods excel in scenarios with small-scale problems and well-defined constraints, where the computational complexity remains manageable. However, their primary limitation lies in their computational expense, which makes them impractical for handling large and complex RCMPSP instances. As the problem size and resource constraints grow, exact methods may become infeasible due to the exponential increase in computation time and memory requirements. As the RCMPSP is an NP-had problem (Asadujjaman et al. 2023a; Asadujjaman et al. 2023b), thus numerous heuristics, metaheuristics, and hybrid methods are developed to solve the multi-project scheduling problems and their extensions.

5.2 Heuristic methods

Numerous heuristic methods like Lagrangian heuristic (Afra and Kheirkhah 2024), parallel schedule generation scheme (Villafáñez et al. (2019), serial schedule generation scheme (He et al. 2022), minimum activity total slack (Villafáñez et al. (2019), mathematical programming-based heuristic (Chen et al. 2018), priority rules (Yu et al. 2023); heuristic finance-based scheduling are developed to solve the RCMPSP. Their strength lies in their simplicity, ease of implementation, and ability to generate feasible solutions rapidly. They are often based on problem-specific rules and are widely used for real-time decision-making or as initial solutions for more sophisticated optimization techniques. However, these methods may yield suboptimal solutions and are generally less effective for addressing highly complex RCMPSP cases, as they do not guarantee optimality and might overlook global problem structures.

5.3 Metaheuristic methods

On the other hand, it is known that meta-optimization methods can solve the complex problem of scheduling successfully. Metaheuristic methods such as genetic algorithm (Bredael and Vanhoucke 2024, Asadujjaman et al. 2024, Zhang et al. 2022, Chen et al. 2022); immune algorithm (Asadujjaman et al. 2024), biogeography-based optimization (Mozhdehi et al. 2024), tabu search (Haroune et al. (2023), ant colony optimization (Sun et al. 2021), raccoon family optimization (Rauf et al. 2020) stand out for their flexibility and ability to handle medium- to large-scale problems with higher complexity. These methods leverage exploration and exploitation strategies to navigate large solution spaces, making them highly suitable for complex RCMPSP instances. Despite their robustness, metaheuristics can have high computational costs and require careful tuning of parameters to achieve efficient performance. This complexity can sometimes hinder their straightforward application.

5.4 Hybrid methods

Hybrid approaches combine the strengths of multiple methodologies, such as integrating exact methods with metaheuristics, to leverage their complementary advantages. There exists numeroud hybrid approaches to solve the RCMPSP and its extensions. Example includes, surrogation-based genetic algorithm (Asadujjaman et al. 2024, Asadujjaman et al., 2023b), genetic and immune algorithm with forward backward improvement (Asadujjaman et al. 2024), memetic algorithm (Torba etv al. 2024), simulated genetic algorithm (Torba etv al. 2024), heuristic-based genetic algorithm (Gholizadeh-Tayyar et al. 2021), and hybrid differential evolution particle swarm optimization (Wang et al. 2022). Hybrid approach outperforms the stand alone approaches in generation quality solutions (Asadujjaman et al. 2024, Asadujjaman 2023). Hybrid approaches are particularly effective for tackling large-scale problems that demand both high-quality solutions and computational efficiency. However, the design and implementation of hybrid methods can be challenging, as they require a balance between different techniques and significant computational resources.

Table 3. Strength, weakness and key applications of different methods for solving RCMPSP

Methods	Strengths	Weaknesses	Key applications
Exact	Guarantees optimal solutions; uses methods like integer programming	Computationally expensive; impractical for large, complex problems	Small-scale problems with well-defined constraints
Heuristic	Quick solutions; easy to implement; problem-specific rules	May provide suboptimal solutions; less effective for highly complex problems	Real-time decision-making, initial solutions for optimization
Metaheuristic	Flexible and powerful	Computational cost can be high; tuning parameters can be complex	Medium-to-large-scale problems; complex
Hybrid	Combines strengths of multiple approaches (e.g., exact and metaheuristics)	Can be complex to design and implement; computational requirements may vary	Complex, large-scale problems requiring high-quality solutions

Table 4. presents a summary of different solution methods used to solve the RCMPSP and its extensions

Solution method	Related works
Exact	Constraint programming (Hauder et al. 2020, Liu and Wang 2010), chance constrained programming (Beşikci et al. 2015), dynamic programming (Satic et al., 2022), mixed integer programming (Aghileh et al., 2024, Hauder et al., 2020), branch & bound (Aghileh et al., 2024)
Heuristic	Lagrangian heuristic (Afra and Kheirkhah 2024), parallel schedule generation scheme (Villafáñez et al. (2019), serial schedule generation scheme (He et al. 2022), minimum activity total slack (Villafáñez et al. (2019), mathematical programming-based heuristic (Chen et al. 2018), priority rules (Yu et al. 2023); heuristic finance-based scheduling (Elazouni 2009)
Metaheuristic	Genetic algorithm (Bredael and Vanhoucke 2024), Asadujjaman et al. 2024, Zhang et al. 2022, Chen et al. 2022); immune algorithm (Asadujjaman et al. 2024), biogeography-based optimization (Mozhdehi et al. 2024), tabu search (Haroune et al. (2023), ant colony optimization (Sun et al. 2021),), raccoon family optimization (Rauf et al. 2020)
Hybrid	Subrogation assisted genetic algorithm (Asadujjaman et al. 2024, Asadujjaman et al., 2023b), genetic and immune algorithm with forward backward improvement (Asadujjaman et al. 2024), memetic algorithm (Torba et al. 2024), simulated genetic algorithm (Torba et al. 2024), heuristic-based genetic algorithm (Gholizadeh-Tayyar et al. 2021), hybrid differential evolution particle swarm optimization (Wang et al. 2022)

6. Discussion

The examination of literature on scheduling methods for multiple projects with limited resources shows a diverse range of research dedicated to solving the challenges of managing several projects under constraints. Between 2005 and 2024, researchers have examined various methods, algorithms, and strategies to boost scheduling effectiveness, optimize resource distribution, and enhance project outcomes.

One of the significant aspects that emerged from the review of the literature is a mathematical modeling and simulation methods employed for effective problem-solving. The scientists have developed sophisticated mechanisms for resolving different issues like scarce resources, interdependent activities, and uncertainty. These models make it possible to regard a number of scheduling issues, restrictions, and complete project pluses in time and order decisions made to complete them more efficiently. There has also been research on the development and assessment of algorithms to solve dynamic and uncertain scheduling problems, with researchers inventing different algorithms for this purpose. For quite a long time, a variety of methods such as genetic algorithms, evolutionary computation, metaheuristic approaches, and pure heuristics have been employed to solve the scheduling problems with many objectives and constraints and complexity. As quantum computing, blockchain, and artificial intelligence technologies develop, they bring new aspects into a project schedule meaning both advantages and challenges.

These technologies enable the tackling of complex scheduling problems with advanced scheduling systems, improving the project control systems, and the management of the project in terms of monitoring and controlling the project at each given time.
Further, the existing studies stress the need to take sustainability and environmental issues into consideration while making project schedules. Some researchers focused on the issue of social project management and proposed the integration of circular economy ideas, environmental protection criteria, and social norms of behavior into the considerations making scheduling decisions.

7. Conclusion

The review emphasizes the noteworthy advancements achieved in RCMPSP models and solutions using both conventional and cutting-edge approaches. In conclusion, the reviewed sources underscore the relevance of techniques for scheduling multiple projects with limited resources in modern day project management. For large-scale applications, exact methods are precise but constrained by processing limitations; in contrast, heuristic and metaheuristic approaches provide best solution for intricate project contexts with limited resources. Recent studies indicate that hybrid models, which include several methods, can successfully strike a compromise between computational effectiveness and solution quality, making them appropriate for practical uses with providing quality solutions. The changes in mathematical modeling, algorithmic, as well as the introduction of new technologies have significantly improved project scheduling systems.

However, there are still other challenges and opportunities to note namely the need for more research on the management of uncertainty, the broadening of approaches for large scale project portfolios and the issue of sustainability and real-time adaptability among others. Therefore, it is important to emphasize that both the researchers and the practitioners need to continue their efforts in searching for new solutions for project scheduling problems in conditions of limited resources. The capacity for managing complex project portfolios in an organization can be enhanced by use of advanced approaches, application of technology, and by ensuring that sustainability considerations are embedded in all operations.

It is important to note the limitations of the current research approach. There were some efforts to explore the present literature exhaustively, but the range and the coverage of the review may have been affected by the databases for papers and the keywords used. In addition, excluding publications in languages other than English must have introduced a certain degree of language bias. However, despite these limitations, this particular research approach provides a systematic framework for aggregating and synthesizing available literature on resource-constrained multi-project scheduling techniques in a given period of time. Although theoretical advancements are emphasized, the practical implementation of these methods in real-world industrial contexts may not be thoroughly discussed. More comprehensive validation of methods through diverse real-world case studies and collaboration with industries could strengthen the practical relevance of findings.

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