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OPTIMIZATION OF REPETITIVE PROJECTS SCHEDULING IN CONSTRUCTION: ANALYSIS FOR THE STATE-OF-THE-ART METHODS

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ABSTRACT

Construction projects which involve multiple similar units and a set of activities that is repeated in these units are knows as repetitive projects. Repetitive projects optimization is crucial for the project to succeed and to achieve its objectives. As a result, several optimization methods have been developed to satisfy several optimization objectives. These methods usually consider the most important constraints and factors that can impact the repetitive project schedule. These methods can be grouped into three groups: mathematical, heuristic, and metaheuristic methods. This paper investigated the developed methods to identify their objectives, implications, main features and limitations. The most important constraints that may affect repetitive projects were also examined to be used in further optimization models. A quantitative analysis for the developed methods is also addressed in the paper. On the basis of this work, implications and guidelines for future research are addressed to enhance repetitive projects optimization and to cover the current unresolved problems.

KEYWORDS: Repetitive projects; Construction planning; Scheduling; Optimization.

أَمْثَلَة جدولة المشاريع التكرارية في التشييد: تحليل أحدث الطرق

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الملخص

مشاريع التشييد التي تشمل العديد من الوحدات المتشابهة و مجموعة من الأنشطة التي تتكرر في هذه الوحدات تسمي المشاريع التكرارية. تعتبر أَمْثَلَة المشاريع التكرارية مصيرية من اجل نجاح المشروع و تحقيق اهدافه. و بالتالي، تم تطوير العديد من طرق الأمثلة من أجل تحقيق أهداف الأَمْثَلَة المتعددة. و هذه الطرق عادةً ما تأخذ في الاعتبار العديد من القيود التي تؤثر علي الجدول الزمني للمشروع التكراري. يمكن تقسيم هذه الطرق إلي ثلاث مجموعات: الطرق الرياضية، الطرق الاستدلالية، و الطرق الاستدلالية العليا. تقوم هذة الورقة البحثية بفحص و التحقق من الطرق المطورة الحالية لتحديد الأهداف، و التضمينات و الاعتبارات، و الخصائص الرئيسية، و أوجة القصور بها. لقد قام البحث أيضاً بفحص أهم القيود التي قد تؤثر علي المشاريع التكرارية من أجل استخدامها في نماذج الأمثلة

المستقبلية. تم عمل تحليل كمي أيضاً للطرق المطورة في هذا البحث. بناءاً علي هذا العمل، تم تناول و توضيح التضمينات و الاعتبارات و التوجيهات للابحاث المستقبلية من أجل تحسين أمثلة المشاريع التكرارية و تقديم حلول للمشاكل الحالية.

الكلمات المفتاحية: المشاريع التكرارية، تخطيط التشييد، الجدولة الزمنية، الأَمْثَلَة.

1. INTRODUCTION

Construction projects which involve a set of activities that are repeated in multiple similar units are known as repetitive construction projects (Reda 1990). These projects can be classified into two types: (1) vertical repetitive projects such as high-rise buildings, and (2) horizontal repetitive projects such as pipeline construction, highway construction, and housing compounds (Hegazy and Wassef 2001). They also can be classified according to the quantities of work into two groups: (1) typical projects in which project units have identical quantities and durations, and (2) atypical projects in which project units have different quantities and durations from each other (Moselhi and El-Rayes 1993). Repetitive construction projects have drawn the attention of all researchers as it represents a considerable volume of the construction industry (Ammar 2020).

In these projects, when the activity is finished in one unit, it will be repeated in another one using the same resources (Huang et al. 2016). This is known as the work continuity constraint. Achieving work continuity for project resources by the project planner ensures the efficient use of resources because it will: (1) reduce the idle time of project resources, (2) increase the learning of the labors, which will save cost and time, (3) reduce the extra time and cost of re-preparing the works due to the idle time of resources (Talodhikar and Pataskar 2015).

Effective planning for construction projects is believed to reduce the project duration, total cost, and construction disputes (Callahan et al. 1992). Accordingly, effective scheduling and optimizing resources for repetitive construction projects is a cornerstone for project success and enhancing the construction industry (Ammar 2020). Furthermore, building optimization models for construction repetitive projects provides the project managers and planners with the optimum schedules that achieve the project objectives, ensure project success, and increase the company’s profit (Monghasemi and Abdallah 2021).

In this paper, the factors affecting repetitive projects scheduling, repetitive projects optimization problems, the techniques used to optimize repetitive projects for different objectives, and implications for future research are addressed.

2. REPETITIVE PROJECTS SCHEDULING

Several scheduling methods have been developed in the literature to schedule construction projects. The critical path method (CPM) is the most used method in scheduling projects (Jaafari 1984). Despite its wide use in construction scheduling, it did not prove the efficiency in scheduling repetitive construction projects because: (1) a huge number of activities is required to represent the repetitive project because it consists of multiple units, (2) it will involve a huge number of redundant relationships to represent the repetitive project, and (3) it does not ensure the achievement of crew work continuity (Reda 1990; Ammar 2020). Against these limitations, the resource-driven methods were developed to provide support for project planners to schedule and represent repetitive projects easily and practically. They ensure the fulfillment of crew work continuity constraints and can provide an easy presentation for repetitive activities (Ammar 2020). They include methods such as line of balance (LOB) (Carr and Meyer 1974), linear scheduling method (Chrzanowski and Johnston 1986), and the vertical production method (O'Brien 1975). In addition to previous methods, several research studies in the literature have modified the previous methods to schedule and optimize repetitive projects with different objectives considering several factors and constraints.

3. FACTORS AFFECTING REPETITIVE PROJECTS SCHEDULING

It is required to account for all factors that can impact the scheduling of repetitive projects in order to produce practical and reliable schedules. In the following sections, the factors that have a major impact on the duration and cost of repetitive projects are explored. **Figure 1** shows the most important factors and parameters.

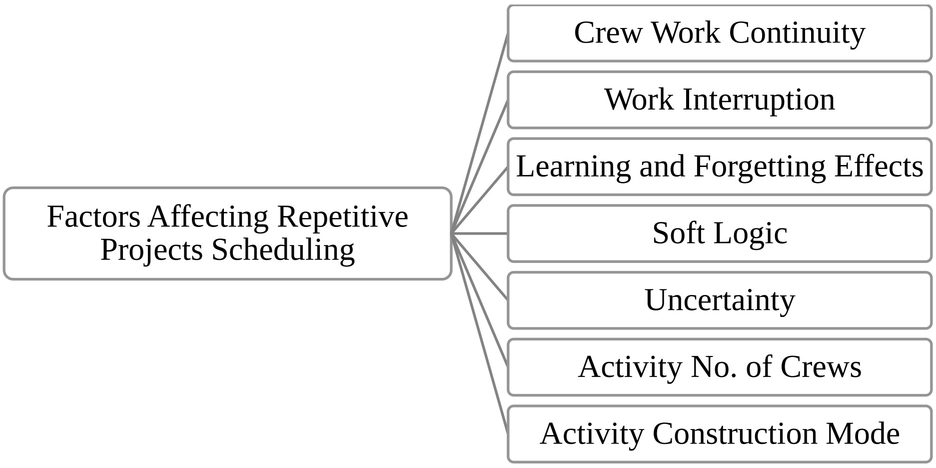

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Figure 1: Factors affecting repetitive projects scheduling

3.1 CREW WORK CONTINUITY AND INTERRUPTION ALLOWANCE

The major advantage of resource-driven scheduling methods is their ability to achieve crew work continuity. Although maintaining work continuity can improve labor productivity (Altuwaim and El-Rayes 2018), its strict implementation can increase the overall project duration and, consequently, the indirect cost (Zou and Zhang 2020). It is argued that tolerating limited interruption for the crews while executing the work can reduce the project duration and, consequently, the indirect cost (Hyari and El-Rayes 2006). However, applying work interruption will decrease the learning phenomenon and will increase the idle time of crews and the associated idleness cost (Altuwaim and El-Rayes 2018). **Figure 2** shows the impact of applying interruption on the project duration.

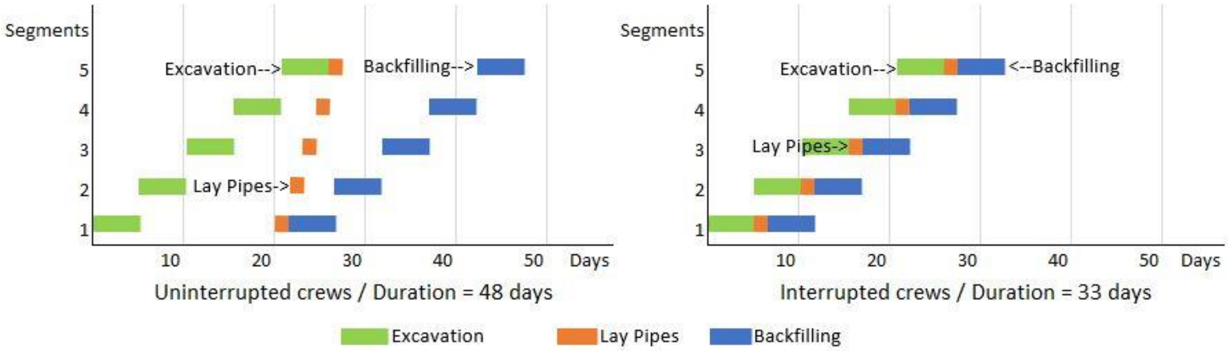

Figure 2: Reduction in project duration due to applying interruption.

3.2 LEARNING AND FORGETTING EFFECTS IN REPETITIVE PROJECTS

Learning development occurs when the crews repeat their task multiple times. This phenomenon of learning is associated with more efficient use of tools, increased familiarity with the work, and better coordination while performing the task (Thomas et al. 1986). The learning effect reduces the duration and cost of each activity and consequently reduces the project duration and cost (Amor and Teplitz 1993). Repeating the tasks is of the nature of repetitive projects. Therefore, considering learning effect while scheduling and optimizing repetitive projects will reduce the project duration and cost, which leads to higher accuracy in forecasting the resource requirements, the projects duration, and total cost (Ammar and Abdel-Maged 2017).

In the literature, three common models were used to incorporate the learning effect into the project schedule. These models were investigated by Thomas et al. (1986) and they include: (1) the Boeing model, also known as the straight-line model, which assumes a constant learning rate for the activity and is the most used model in construction scheduling, (2) the Stanford "B" model, which is a modification to the Boeing model to consider the acquired experience, and (3) the cubic model which assumes a variant learning rate for the activities. To the extent of the author's knowledge, no model could consider the learning effect in the optimization of repetitive projects. However, few research studies considered the learning effect in modeling repetitive projects only. For example, Ammar and Abdel-Maged (2017) modified the Boeing model to consider multiple numbers of crews for each activity. The model could reduce the project duration compared to the traditional LOB scheduling.

3.3 SOFT LOGIC IN REPETITIVE PROJECTS

The sequence between activities in construction projects plays a vital role in determining the overall project duration. In construction, there can be multiple options of sequence between activities (Fan et al. 2012). According to Tamimi and Diekmann (1988), there are two types of activities sequence: (1) hard logic, which is fixed and cannot be changed through the project and represents mandatory or physical constraints; and (2) soft logic which represents different sequencing scenarios for each activity and the tasks can be performed in parallel or in sequence. Soft logic can exist in repetitive projects such as housing projects, highway construction, and other infrastructure projects, which include several spatially distributed units (Zou and Zhang 2020). For example, in a housing project, installing wooden formwork activity can be executed in unit "1" then unit "2", or unit "2" then unit "1", or the two units can be executed in parallel. However, the time and cost of transferring resources between different units should be accounted for while optimizing the sequence of repetitive project. Considering soft logic and optimizing the sequence of the repetitive activities in different units is necessary to produce effective schedules that reduce the project duration and cost (Zou and Zhang 2020).

3.4 UNCERTAINTY IN REPETITIVE PROJECTS

Most repetitive projects optimization models only deal with deterministic inputs, and only a few research studies considered uncertainties of the scheduling inputs such as quantities of work, costs, labor productivity, and resources availability (Bakry et al. 2016; Salama and Moselhi 2019). Integrating uncertainty in the optimization of repetitive projects scheduling is expected to represent the actual status and progress of the project, thus reducing the time and cost overruns (Bakry et al. 2016).

4. REPETITIVE PROJECTS OPTIMIZATION

Optimization of repetitive projects is necessary to produce realistic schedules. It ensures achieving the project objectives and increases the competitiveness of any company during the bidding process. Optimization of repetitive projects is different from optimization of traditional construction projects because it must consider the crew work continuity constraints, and the problem size is usually big due to the multiple numbers of repetitive units (Bakry et al. 2016). In the literature, optimization is done to achieve different objectives such as: (1) minimizing overall project duration, (2) minimizing the total cost, (3) minimizing idle time of crews, (4) maximize crew work continuity, (5) optimizing the logic relationships between different units, and (6) maximizing the investment profit (Esfahan and Razavi 2015; Monghasemi and Adallah 2021).

Several methods and techniques have been proposed to optimize repetitive projects to achieve the above-mentioned optimization objectives. These methods can be divided into three main categories: (1) mathematical methods (Ipsilandis 2007; Liu and Wang 2012; Elrayes and Moselhi 2001), (2) heuristic methods (Zhang et al. 2006), and (3) meta-heuristic models (Long and Ohsato 2009; Eid et al. 2012). Most of the developed models only deal with deterministic inputs. However, other stochastic models may consider uncertainty in the scheduling inputs (Bakry et al. 2016; Salama and Moselhi 2019). **Figure 3** shows the repetitive projects optimization objectives and methods.

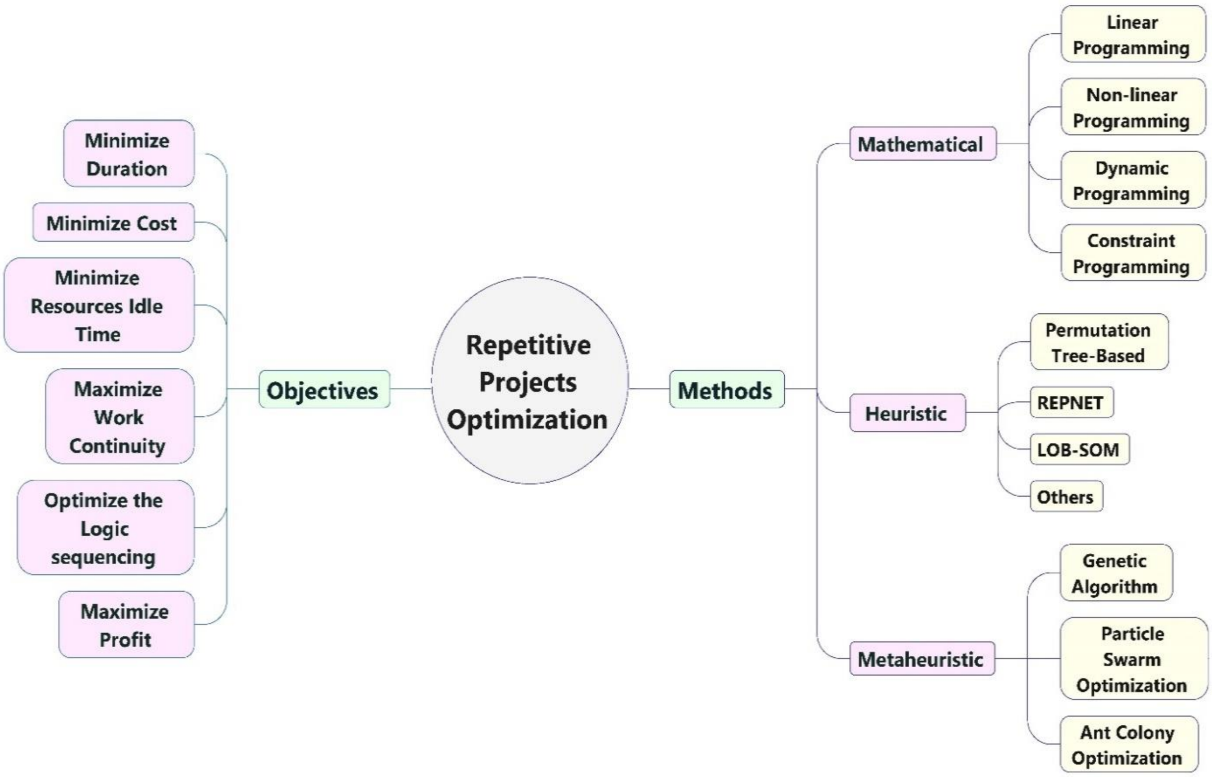

Figure 3: Repetitive projects optimization objectives and methods

4.1 MATHEMATICAL METHODS

Mathematical methods require the problem, its constraints, and its objective function to be explicitly formulated (Zhou et al. 2013). This will be hard and time-consuming for construction schedulers who lack the adequate knowledge and will not be suitable for solving complex problems. Mathematical methods can be grouped into four groups: (1) linear programming, (2) non-linear programming, (3) dynamic programming, and (4) constraint programming.

Mathematical methods have been used widely to optimize repetitive projects. For example, Reda (1990) have proposed a linear programming model to minimize the project direct cost. The model considers the activities time-cost curve to shorten activities duration to achieve a constant rate of production for each crew. Huang and Halpin (2000) developed a graphic linear programming model to optimize the project overall rate. Ipsilandis (2007) developed a linear programming model that integrates the multiple elements of total duration, units' delivery dates, and the idle time of resources into one objective function. Zou et al. (2017) developed a mixed-integer linear programming model to identify the optimal number of crews that minimizes total cost for typical repetitive projects. García-Nieves et al. (2019) introduced a linear programming model that can minimize whether project duration or cost while allowing interruption to the work. Ammar (2019) developed a non-linear programming model to achieve minimum project duration while allowing interruption to the activities; however, the model cannot guarantee achieving optimality. Monghasemi and Abdallah (2021) proposed a linear programming model to minimize the total cost and work interruption while considering soft logic.

Moselhi and El-Rayes (1993), and Senouci and Eldin (1996) identified the optimum crew size for the activities to minimize total cost by using dynamic programming models. Elrayes and Moselhi (2001), and El-Rayes (2001) developed dynamic programming models to minimize the project duration while allowing interruption for the activities. Moselhi and Hassanein (2003) introduced a dynamic programming algorithm integrated into an object-oriented model to optimize whether project duration or cost while considering multiple crew numbers for each activity. Bakry et al. (2016) introduced the first model to consider uncertainty in scheduling inputs while optimizing the repetitive project. The model uses a fuzzy dynamic programming algorithm to minimize the project duration and cost while considering multiple construction modes for each activity.

Liu and Wang (2012) introduced a constraint programming model to optimize the overall project duration while considering multi-skilled crews to improve the labors production rate. Zou and Zhang (2020) introduced a constraint programming model to minimize the project total cost. The model allows interruption for the activities and considers the soft logic to find the optimum sequence between units.

Although mathematical methods can yield accurate results, they are not suitable to schedule large-scale problems as they will require large computational effort (Zhou et al. 2013). For example, the model developed by García-Nieves et al. (2019) cannot handle large scale problems and the authors, based on their findings, suggested to use metaheuristic methods to overcome the computational limitations. Table 1 summarizes the objectives and considerations of the previous mathematical models to optimize repetitive projects.

Table 1: The previous mathematical repetitive scheduling optimization models

Technique	Source	Optimization Objective				Allow Inter.	Learn.	Soft Logic	Four Relation Types	Multiple Relations	Multiple no. of Crews	Multiple Const. Modes
		Dur.	Cost	Inter.	other							
Linear Programming	(Reda 1990)		Y							Y		Y
	(Huang and Halpin 2000)				Y							Y
	(Ipsilandis 2007)	Y			Y	Y				Y		
	(Zou et al. 2017)	Y	Y								Y	
	(García-Nieves *et al.* 2019)	Y	Y			Y			Y	Y		
	(Monghasemi and Abdallah 2021)		Y	Y	Y	Y		Y				
Non-linear programming	(Ammar 2019)	Y				Y					Y	
Constraint Programming	(Liu and Wang 2012)	Y				Y			Y			
	(Zou and Zhang 2020)		Y			Y		Y	Y		Y	
Dynamic Programming	(Moselhi and El-Rayes 1993)		Y						Y			Y
	(Senouci and Eldin 1996)		Y						Y	Y		Y
	(Elrayes and Moselhi 2001)	Y				Y			Y	Y		Y
	(El-Rayes 2001)	Y				Y			Y			Y
	(Moselhi and Hassanein 2003)	Y	Y						Y	Y	Y	
Fuzzy Dynamic Programming	(Bakry *et al.* 2016)	Y	Y								Y	Y

4.2 HEURISTIC METHODS

Heuristic methods involve rules put by the model developer and can be based on the previous experience of problem-solving. For example, Zhang et al. (2006) developed a heuristic model that utilizes permutation tree-based algorithm to identify the different combinations of the decision variables for the activities. These combinations are ranked and the combination that will lead to minimum duration and cost will be selected. The model considers multiple number of crews and multiple construction modes for each activity but does not allow work interruption. Bragadin and Kahkonen (2011) developed a heuristic model called REPNET that is based on a precedence diagram drawn upon a resource-space graph. The model aims at minimizing the idle time of resources and can allow interruption to the activities. Zou et al. (2018) introduced a bi-objective exact model called LOB-SOM that allows interruption and can minimize the activities number of crews and maximize the work continuity to finish the project within the given deadline.

Heuristic optimization approaches require less computational effort than the mathematical approaches. They have been used widely in the scheduling problems because they are simple and easy to implement. The main limitation of the heuristic methods is that the method depends on the specific problem and cannot be applied to all cases (Zhou et al. 2013). For example, Zou et al. (2018)

customized the ϵ-constraint method to find the optimal solutions for the deadline satisfaction problem in line of balance. Table 2 summarizes the objectives and considerations of the previous heuristic models to optimize repetitive projects.

Table 2: The previous heuristic repetitive scheduling optimization models

Technique	Source	Optimization Objective				Allow Inter.	Learn.	Soft Logic	Four Relation Types	Multiple Relations	Multiple no. of Crews	Multiple Const. Modes
		Dur.	Cost	Inter.	other							
Permutation Tree-based	(Zhang *et al.* 2006)	Y	Y							Y	Y	Y
REPNET	(Bragadin and Kahkonen 2011)			Y		Y					Y	
LOB-SOM	(Zou *et al.* 2018)	Y				Y				Y	Y	

4.3 METAHEURISTIC METHODS

Metaheuristic methods are used to solve large scale problems whose optimum solution can exist beyond a discrete searching pool (Zhou et al. 2013). These methods perform iterative computation against certain criteria to find the optimal or near-optimal solutions. Metaheuristic methods are usually inspired from the nature such as: (1) genetic algorithm (GA), which is the most used method, (2) particle swarm optimization (PSO), and (3) ant colony algorithm (ACA). These methods are used widely to solve repetitive projects optimization. For example, Hegazy and Wassef (2001), and Elbeltagi et al., (2007) could identify the optimum construction mode, and crew number for the activities while allowing interruption to achieve the minimum total cost using genetic algorithm models. Hyari and El-Rayes (2006) developed a genetic algorithm model to minimize the project duration while allowing interruption for the activities. The model considers multiple construction modes for the activities. Srisuwanrat and Ioannou (2007) developed a genetic algorithm to maximize the profit while allowing interruption and taking probabilistic durations into consideration. Senouci and Al-Derham (2008) introduced a genetic algorithm model to find the solution with minimum duration and cost. The model did not allow the interruption to the works and utilized a single crew for each activity. Long and Ohsato (2009), and Hyari et al (2009) introduced genetic algorithm models to identify the optimal solution that gives both minimum duration and cost. The models allow the interruption to the activities and consider multiple construction modes for each activity. Huang and Sun (2009) proposed a genetic algorithms model to maximize the project net present value (NPV). Eid et al. (2012) introduced a Genetic algorithm model that allows for interruption and considers multiple number of crews to minimize the project duration, cost, and interruption time. Huang et al. (2016) proposed a model which utilizes GA to identify the optimum sequence and utilizes linear programming to identify only the optimum start dates for the activities. Altuwaim and El-Rayes (2018) introduced a GA model to minimize whether overall project duration or interruption time; however, the model does not guarantee optimality. Salama and Moselhi (2019) proposed a fuzzy GA model that considers uncertainty in the scheduling inputs while optimizing the repetitive project. The model can minimize the project duration, cost, and interruption while considering multiple number of crews for each activity. Heravi and Moridi (2019) proposed a particle swarm optimization model that considers the idle cost of resources and multiple crew numbers for each activity to minimize both project duration and cost. Tran et al. (2020) have proposed a genetic algorithm model that considers multiple number of crews for each activity and maintaining work continuity to optimize atypical projects. Genetic algorithm is the most frequently used method in optimizing repetitive projects. It is based on searching the solution randomly. Hence, it is suitable to solve large-scale problems in which large searching pools exist. However, global optimum solutions are not guaranteed due to the random searching algorithm, which makes it hard to define the algorithm stopping condition (Zhou et al. 2013). Table 3 summarizes the objectives and considerations of the previous metaheuristic models to optimize repetitive projects.

Table 3: The previous metaheuristic repetitive scheduling optimization models

Technique	Source	Optimization Objective				Allow Inter.	Learn.	Soft Logic	Four Relation Types	Multiple Relations	Multiple no. of Crews	Multiple Const. Modes
		Dur.	Cost	Inter.	other							
GA	(Hegazy and Wassef 2001)		Y			Y				3 Only	Y	Y
	(Hyari and El-Rayes 2006)	Y				Y			Y	Y		Y
	(Elbeltagi *et al.* 2007)		Y			Y					Y	Y
	(Srisuwanrat and Ioannou 2007)				Y	Y						
	(Senouci and Al-Derham 2008)	Y	Y							Y		Y
	(Long and Ohsato 2009)	Y	Y			Y				Y		Y
	(Hyari *et al.* 2009)	Y	Y			Y						Y
	(Huang and Sun 2009)				Y					Y	Y	
	(Eid *et al.* 2012)	Y	Y	Y		Y					Y	Y
	(Huang et al. 2016)	Y	Y					Y		Y		Y
	(Hyari and El-Rayes 2004)	Y		Y		Y						Y
	(Altuwaim and El-Rayes 2018)	Y		Y		Y			FS / SS			
Fuzzy GA	(Salama and Moselhi 2019)	Y	Y	Y		Y						Y
PSO	(Heravi and Moridi 2019)	Y	Y			Y				Y	Y	

5. QUANTITATIVE ANALYSIS OF THE PREVIOUS WORK

The performed extensive review made it possible to perform quantitative analysis for the previous model to identify the current implications and shortcomings for these methods and to set up the guidelines for future improvement. This analysis can be performed from different perspectives such as: optimization objectives, optimization methods, and research considerations.

First, the optimization objectives can be analyzed as shown in **Figures 4** and **5**. It is observed that half the work focused on developing single objective models while the other half focused on building multi-objective models. Also, the most frequently targeted objective is minimizing time, followed by minimizing cost, then minimizing interruption. Objectives such as optimizing sequence, profit, overall construction rate are less focused on, with no previous work to optimize quality and risk.

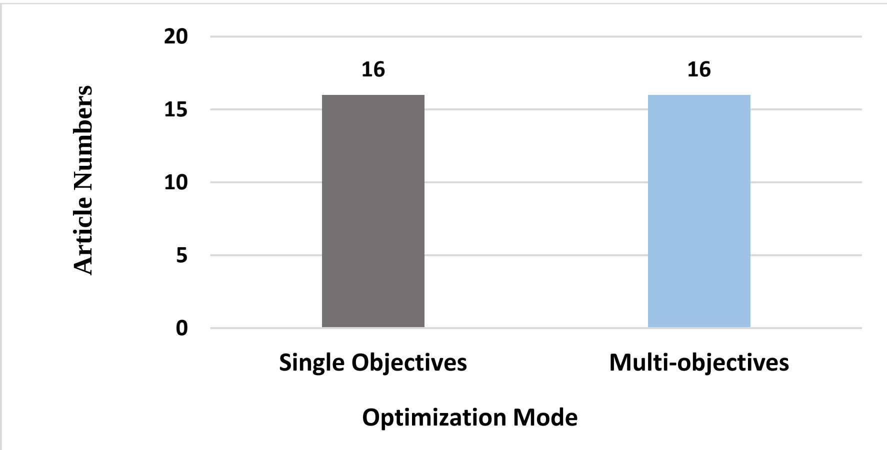

Figure 4: Number of articles according to the optimization mode

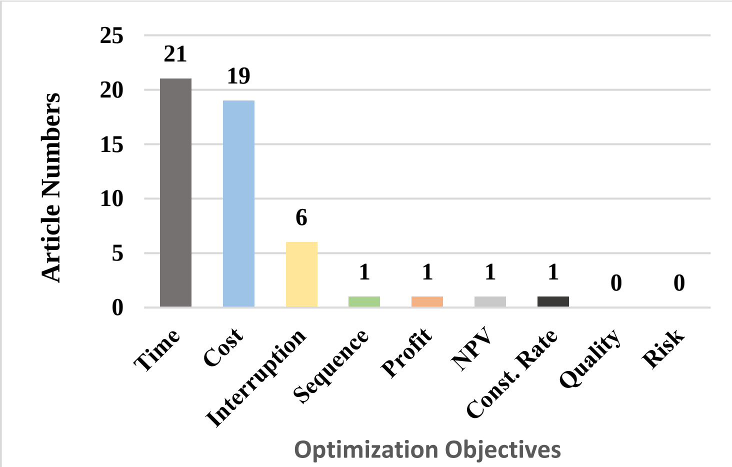

Figure 5: Number of articles according to the optimization objectives

Second, optimization methods can be analyzed as shown in **Figures 6** and **7**. Mathematical methods are the most used followed by metaheuristic methods. The most frequently used method is the genetic algorithm because of its capability to solve large-scale problems. Linear and dynamic programming methods comes after genetic algorism because they can guarantee optimality. However, it is hard to solve complex problems by using them.

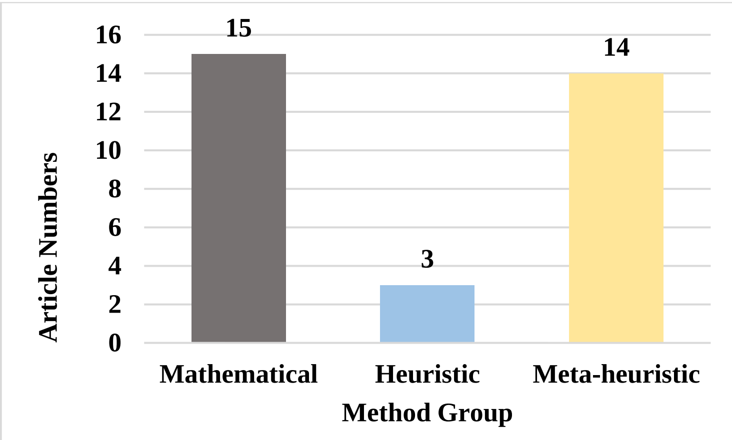

Figure 6: Article numbers according to optimization method group

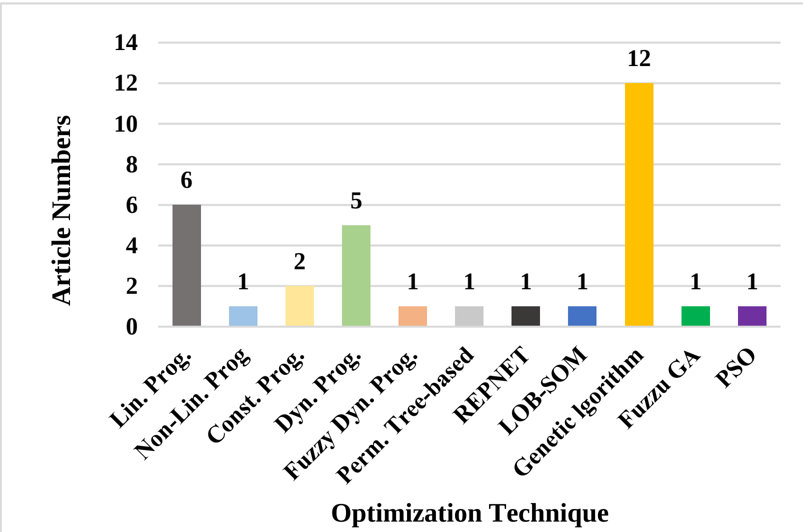

Figure 7: Article numbers according to the optimization technique

Third, the consideration of each of the developed methods are indicated in **Figure 8**. It is clear that interruption is the most considered factor, followed by multiple construction modes, then multiple no. of crews. **Figure 8** also shows that only a few research studies considered soft logic and uncertainty, while no model considered the learning and forgetting effects during optimizing the repetitive project.

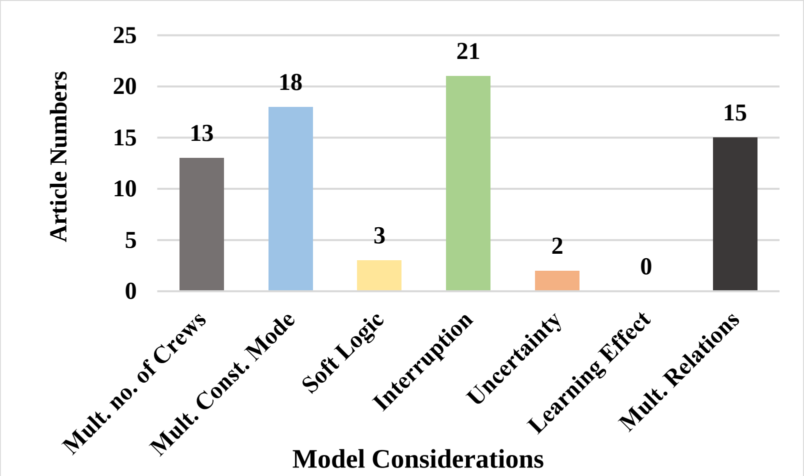

Figure 8: Article numbers according to the model considerations

6. DISCUSSION AND CONCLUSIONS

Repetitive projects optimization has been studied by several researchers because of the considerable importance of repetitive projects. Optimization objectives can be: (1) minimizing overall project duration, (2) minimizing total cost, (3) minimizing idle time of crews, (4) maximize crew work continuity, (5) optimizing the logic relationships between different units, and (6) maximizing the investment profit. Several methods have been developed to achieve these objectives such as: (1) mathematical methods which include linear programming, non-linear programming, dynamic programming, and constraint programming; (2) heuristic methods which include permutation tree-based, REPNET, LOB-SOM, and other methods; and (3) meta-heuristic methods such as genetic algorithm, particle swarm algorithm, and ant colony algorithm.

Mathematical methods require the problem to be explicitly formulated. This will be hard and time-consuming for construction schedulers and will not be suitable for solving complex problems because of the large computational effort. Heuristic approaches are simple, easy to implement, and require less computational effort than mathematical approaches. However, their main limitation is that they depend on the specific problem and cannot be generalized to be applied to all cases. Metaheuristic methods can solve large-scale problems. These methods perform iterative computation against certain criteria to find the optimal or near-optimal solutions. The most frequently used method is the genetic algorithm. It is based on random searching for the solution. Hence, it is suitable to solve large-scale problems, but global optimum solutions are not guaranteed, and it is hard to define the algorithm stopping condition.

Defining constraints during optimization is crucial to ensure the accurate definition of the problem to be solved. In repetitive projects, it is necessary to consider as many constraints as possible during optimizing the project to produce realistic and practical schedules that can be adopted by construction managers. After performing an extensive review of the literature, the authors have discovered that the learning and forgetting effects have not been considered in any optimization model, although they have a significant impact on the project duration and cost. Also, soft logic and resources transfer cost and time are considered in only a few research studies. It is suggested for future research in repetitive projects optimization to consider the learning and forgetting effects, and soft logic to guarantee that the optimum solution is feasible and practical. It is also noted that each research study only considers few constraints simultaneously. It is recommended for future research to consider all the constraints that affect the project duration and cost such as: crew work continuity, allowing interruption, learning effect, soft logic, uncertainty, multiple crews, and multiple construction modes. This will require repetitive projects schedulers and researchers to develop an efficient optimization model that considers all these constraints while optimizing the project for different multi-objectives such as minimizing project duration and cost. This will ensure getting practical global optimum solutions.

It is also recommended that future research focuses on optimizing the repetitive projects for other objectives such as maximizing quality and minimizing construction risk in addition to solving the traditional time-cost tradeoff. Although quality and risk are crucial for the success of any project, they were not addressed in previous repetitive projects optimization models.

This paper introduced a comprehensive state-of-the-art review for repetitive projects optimization, upon which project schedulers and researchers can rely to identify the implications and shortcomings of the previous optimization methods. This paper is also believed to stimulate future research to improve repetitive projects optimization and cover the discussed unresolved problems.

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