Time-Cost Tradeoff and Resource-Scheduling Problems in Construction: A State-of-the-Art Review

Ali F. Elkliny[1], Haytham M. Sanad[2], Emad E. Etman[3]

[1] Demonstrator at Structural Eng. Dept., Faculty of Engineering, Tanta University, Egypt
[2]Lecturer at Structural Eng. Dept., Faculty of Engineering, Tanta University, Egypt
[3]Professor emeritus, Structural Eng. Dept., Faculty of Engineering, Tanta University, Egypt
Email: Ali.Fathy@f-eng.tanta.edu.eg haytham.sanad@f-eng.tanta.edu.eg emad.etman@f-eng.tanta.edu.eg

Abstract- **Duration, cost, and resources are defined as constraints in projects. Consequently, Construction manager needs to balance between theses constraints to ensure that project objectives are met. Choosing the best alternative of each activity is one of the most significant problems in construction management to minimize project duration, project cost and also satisfies resources constraints as well as smoothing resources. Advanced computer technologies could empower construction engineers and project managers to make right, fast and applicable decisions based on accurate data that can be studied, optimized, and quantified with great accuracy. This article strives to find the recent improvements of resource-scheduling problems and time-cost trade off and the interacting between them which can be used in innovating new approaches in construction management. To achieve this goal, a state-of-the-art review, is conducted as a literature sample including articles implying three areas of research; time-cost trade off, constrained resources and unconstrained resources. A content analysis is made to clarify contributions and gaps of knowledge to help suggesting and specifying opportunities for future research.**

Keywords- **Time-cost trade off; Constrained resources; Unconstrained resources; Multimode; Construction method; resource scheduling.**

I. INTRODUCTION

There are various constraints in construction projects that include, but not limited to, project duration, cost, quality, and resources. Thus, construction projects' management are difficult, include many jobs and tasks that are tightly tied to each other, and have many complex aspects to them. Decisions on construction methods as well as staff and equipment resource allocations have a substantial impact on project cost, quality and finishing date [1]. As a result, construction managers do their best to ensure that the project is executed as it was planned. They consistently strive to complete the projects on the planned duration and aimed budget. [2].

Project objectives may include duration, cost, quality, and resource. In each project, one of these objectives can be of high importance compared to other objectives. Balancing between these objectives is one of the best project manager's skills [3]. Choosing the best alternative of each activity to minimize project duration and cost satisfying resources constraints and leveling it is one of the most critical, significant and complicated problems in construction project management.

Resource management could be described as a crucial discrete dynamic problem in project management. Because of scarcity of resources, project schedulers suffer from many issues after allocation of resources to the project activities such as increasing in project duration or impractical schedule. Therefore, Researchers and practitioners have researched and implemented resource management broadly. Generally, resource management consists of two main parts; constrained resources and unconstrained resources. From this perspective, constrained resources problem objective is to minimize the total duration (not the cost) of the project, while not exceeding the resource limits [4], it is importance results from its great impact on construction schedules [5]. On the other hand, the unconstrained resources problem aims to balance the resource usage during project life cycle within constant project duration and unlimited resources [6]. The two types together could be called resource-scheduling problems (RSPs). The each part of resource management has its aims and objectives to get solved, so solving RSPs are more complex than solving each part separately.

Time-cost trade off (TCT) is the technique used to overcome critical path method's inability to deal with the scheduled project duration. The project can be accelerated through different methods including adding resources increasing work hours by using multiple shifts to shorten critical activities duration to shorten project duration. Although decreasing project duration results in saving the indirect costs of the project, it also result in increasing the direct costs which leads to tradeoff problem shouldn't be overlooked. Consequently, Several practitioners and researchers have studied TCT analysis problem using various techniques with Artificial Intelligence (AI) [7] and also adding different dimensions to the problem such as quality [8] [9], environmental impact [10], safety [11], or incorporating risk to the problem [12],[13]

In this paper, recent improvements in TCT, RSPs and inter-relationships between them, using a state of art review for most recent articles related to two selected topic. The paper is structured as following; Section 2 describes research methodology, Section 3 displays discussion, however Section 4 illustrates content analysis, and finally, Section 5 demonstrates the conclusion of article and opportunities for future research.

II. RESEARCH METHODOLOGY

The most recent research in the area of construction management related to TCT and/or RSPs is included in this review. Flow chart of adopted research methodology is shown in Fig. 1. As shown research methodology is divided into three stages; Preliminary search stage, Filtering stage, and Review stage. At preliminary search stage the search is conducted about articles published between "2015-2021" to address the two topics in recent articles, which are depending on the previous studies. Powerful and widely used academic search engines are used such as Google Scholar, Scopus and Egyptian Knowledge Bank (EKB) and the keywords that used in the search is including "Time-cost trade off", "Constrained resources", "Unconstrained resources", "Resource allocation", "Resource Smoothing", and "resource scheduling" with consideration for different spellings. As a result, a list of 305 journal articles related to written keywords are found after preforming the search process, in Filtering stage, the following criteria are adopted to get the most related and useful articles:

(1) Conference papers aren't acceptable since their information wasn't as comprehensive as journal articles [14],

(2) articles must be published in indexed journal in Scopus and at least Q4 journal to be acceptable,

(3) English must be used to write the articles. After the aforementioned criteria are reached, Review stage starts with a deep and detailed visual read of the chosen papers was performed to assess the most papers bring into line with the purpose of our review article.

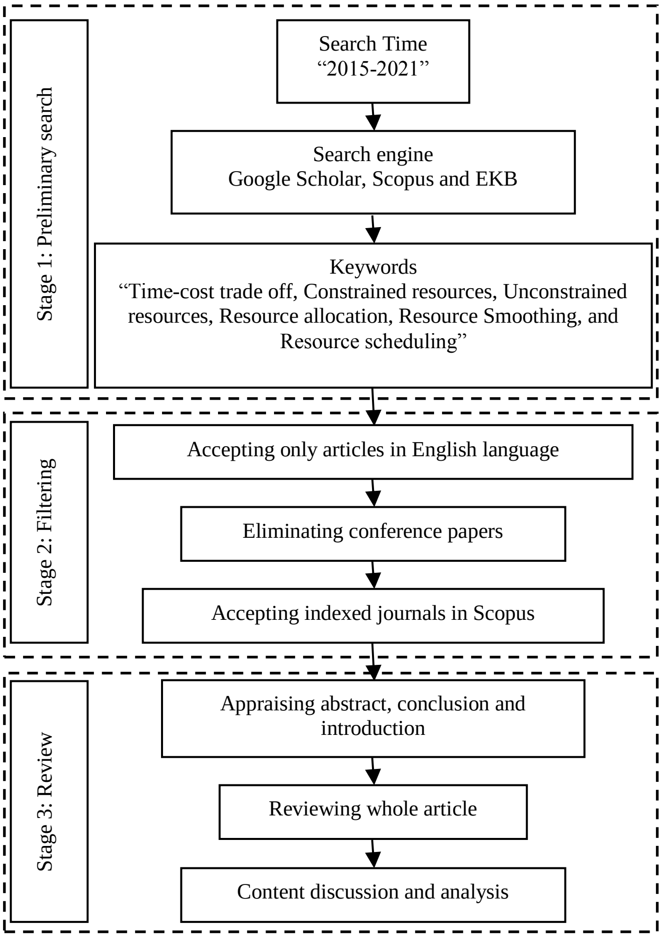

Fig. 1. Research methodology flowchart.

The abstract, introduction and conclusion were appraised, and then whole article was reviewed, if the paper was considered appropriate, then the article content discussion and analysis is performed to show the most related articles to construction industry and adding novel and real development related to the topics. Finally, 30 articles corresponding to the topic are discussed.

III. DISCUSSION

There are three separate parts make up results discussion of the review and describe in brief contribution and comments of the selected articles related to the field of review. First, articles related to constrained resources, followed by, unconstrained resources, and then time-cost trade off.

A. Constrained resources

Yuan et al. [15] formulated a multi-objective multi-mode mathematical model for resource-constrained project scheduling (RCPS) with prefabricated building (PB) construction. Multiple modes and uncertain in execution activity duration were considered. Fuzzy theory was used to define uncertain in activity duration. Moreover, there are two objectives of PB construction project scheduling problem; time-based and cost-based profit. A hybrid cooperative co-evolution algorithm was proposed to produce extremely resilient project scheduling, and decrease uncertainty impact on the whole project. Cooperative co-evolution algorithm, self-adaptive mechanism, and self-adaptive selection process were enhanced and improved in the model. The hybrid cooperative co-evolution algorithm (HCOEA) significantly improved ability of exploration in search space and enhanced the capability to find solution for large size problems. The main gap in the model developed by Yuan et al. [15] is that excluding the uncertain in activity cost. Moreover, quality and unconstrained resource problem weren't included.

Xie et al. [16] presented a new mixed-integer nonlinear programming (MINLP) model for developing Multi-mode RCPS under uncertain in activity cost within decreasing project risk cost overrun as an objective, and obtaining optimal solutions. To obtain a practical solution efficiently and solve the computational problems in accurate method for solving large-scale projects, construction Heuristic (CH) with a multi-pass greedy development procedure is created. CH is designed to minimize expected total project cost which is set as an objective, and then multi-pass greedy development procedure is applied in CH to rapidly provide a high quality solution among large numbers of randomly generated priority lists. A hybrid CH and genetic algorithm (GA) (CH-GA) is developed with a custom fitness function to correctly adjust the quality of an individual for more improving solution quality, when CH obtains the best solution, it is added into the initial population to maintain initial population quality. CH-GA works well for large-scale instances in reasonable duration with substantially less computing time than the exact method, particularly, for the project with sixty and ninety activities instances, which would be significant contribution of the abovementioned model. Excluding uncertain activity duration in solving the multi-mode RCPS could be gap for the model developed by Xie et al. [16]. Also, unconstrained resource problem isn't taken into consideration.

H.-W. Wang et al. [17] developed an integrated approach for construction scheduling that allows easy data flow from the information model to RCPS model. A work package-based information model is presented within this approach to gather all the required data of the RCPS. Then, integrating multisource data by a semi-automatic method is presented to get the proposed information model formed, and to support a developed Multi-mode RCPS (MRCPS) model, an adaptive data transmission method is used. The proposed MRCPS model is developed using constraint programming (CP) to fit the integrated model.

The model's key contribution is that, being a unique integrated method to formalize a construction information model utilizing a semi-automatic data integration approach, which covers the information demand and allows easy flow of data during the RCPS solution process. Additionally, the work package-based information model is a successful effort to present previously acquired knowledge into automated schedule procedures. Also, the research attempts to give insight on how the data integration be automated, model development and solution processes as well as contributes to the current state of practice in using complex RCPSP models in realistic projects. Moreover, this type of data model is very useful in construction management, schedule tracking, cost estimating, and also would be beneficial in avoiding possibility of rework issues besides efforts and mistakes in data entering and editing, as it is a rich data source. In addition, work package templates database presented allows for reuse of previously gained engineering knowledge and increases the efficiency of the entire process. The scope of the approach developed by H.-W. Wang et al. [17] is limited to constrained resources only and excluding unconstrained resource problem, excluding of project cost and quality as well. Also, using mathematical method instead of algorithm such as GA and Particle Swarm Optimization (PSO) to solve the RCPSs would be a gap of the approach.

Chakrabortty et al. [18] presented MRCPS within a fast near-optimum solution, for known deterministic renewable and nonrenewable resource requirements that used by project activities. The MRCPS was solved by using different exact, metaheuristic, and heuristic procedures, as it is known to be nondeterministic polynomial-time hard. So, a modified variable neighborhood search heuristic algorithm is used as an advanced and powerful optimization approach which fits schedule problems. Consequently, the major contributions of the abovementioned research are: introducing an updated parallel schedule generation scheme for MRCPS, to detect right activity among large active activities a dynamic mode selection policy is developed, in any particular instance of time, suggesting a modified approach for neighborhood diversification among the activities that represent an initial unbuffered baseline schedule, and showing how to discover those schedules with improved swapping and choosing mode to discover optimal or near-optimal results.

It was considered comparison with existing methods for the computational experimental study, used project scheduling problem library (PSPLIB) dataset and the following meta-heuristic approaches were considered: GA, hybridization of GA, simulated annealing (SA), PSO, discrete PSO, ant colony optimization, estimation of distribution algorithm, differential evolutionary algorithm, reinforcement learning, and fully informed particle swarm from different authors. Moreover, to get the comparison better, it is also considered a standard set of 4320 newly developed multimode instances from MMLIB50, MMLIB100, and MMLIB+ datasets. With the limit of 50,000 schedules on these datasets, the proposed algorithm gets better makespan for 106, 34, and 1601 instances, respectively, which validates the presented algorithm efficiency, mainly for large-scale projects. The gap of the model developed by Chakrabortty et al. [18] includes but not limited to excluding project cost which is an important objective for construction project management.

Kasravi et al. [2] used imperialist competitive algorithm (ICA) and PSO to create hybrid algorithm of PSO and ICA. The hybrid algorithm was developed to solve RCPS problem. ICA and PSO are population-based algorithms which capable of solving problems with the least possible data. These algorithms are broadly used in solving different and wide range of optimization problems, not only RCPS problems, but also more complex and large problems with more constraints. However, results would have some problems, if one algorithm has been employed individually. For example, if PSO algorithm has been employed separately it will have some drawbacks; the probability of trapped in local optimum, and difficulty in improving the quality of the solutions with more iterations. Also, when using ICA separately isn't preferred since the following weaknesses: premature convergence may occur under different conditions, and search algorithm operation can fail when the problem gets too large. Shortcomings of each algorithm could be mitigated by combining algorithms together. Within the same context, the combination of PSO and ICA algorithms will create a new hybrid algorithm that will help in finding better solutions for RCPS problem. The developed model by Kasravi et al. [2] have some limitations such as: the activities can't be stopped or split , the resources of activity must be renewable. Moreover, it excluded multi-mode in solving RCPS.

Tao and Sasha [19] proposed project structure alternatives when dealing with the MRCPS problem which would be an extension to the traditional MRCPS problem. The problem is developed as a bi-objective linear integer program, which aims at minimizing project makespan and total cost and it could be titled time-cost trade-off MRCPS problem with project structure alternatives. To represent the project with alternative structures, a hybrid metaheuristic is established based on AND-OR network, which nests adopted NSGA-II and Tabu Search. The main advantage of the model is that it can deal with large-scale problems. Furthermore, in industrial applications, this type of project scheduling problem with alternative project structures would be very promising. Also, the algorithm is appropriate and suitable for managers who have different objective preferences, and they make time-cost trading off to be able to make decisions along with this Pareto set. The gaps in the research by Tao and Sasha [19] would be but not limited to neglect the quality of the project when dealing with different alternative project structures as well as safety in the project and their corresponding costs. Also, stochastic in activity duration or resource usage/consumption could be included in the model as a strong effect variable.

Isah and Kim [20] presented a stochastic multi-skilled resource scheduling (SMSRS) model for RCPS by considering duration of each activity as an uncertain value. The SMSRS model was created by combining an existing multi-skilled resource scheduling (MSRS) algorithm developed by Hegazy et al. [21] with a schedule risk analysis (SRA) model that uses Monte Carlo simulation (MCS) and triangular distribution with an MS Excel spreadsheet for the development of a practical and realistic schedule. SMSRS model's main contributions are that: (1) a simple tool for assessing risks related to RCPS allowing construction managers and project practitioners to take response actions in as accurate way as possible; (2) the simplicity of the tool will help small-scale construction businesses in evaluating schedule risks to produce a realistic and practical schedule.

Within the same context, the model will be a useful for the small-scale companies in: (1) accurate estimating of activity duration taking into account risks; (2) estimating costs of the required resources of project activities while avoiding cost overruns; (3) improving activity coordination and ensuring worker safety on-site by experienced multi-skilled labors based on the practical project schedule. The major gap in model by Isah and Kim [20] model that is neglecting project cost as important factor in the project objectives. Excluding project quality which may be affected by using multi-skilling strategy is main gap as well. Moreover, unconstrained problem couldn't take into consideration in the model. Furthermore, SMRS model is limited to small projects which are only 10–20 activities can be studied.

Kaiafa and Chassiakos [22] developed an optimization method to solve multi-objective RCPS which assess several resource-duration options for each activity. The proposed optimization strives to minimize costs that results from: resources over allocation, prolonged project duration; and resource fluctuations. All these sub-objectives are modeled in cost functions after assigning cost values to each deviation from the related objective. The cost components are cost for resource usage titled with direct cost and the penalty costs for beyond project duration set by the owner. In particular, the values of cost for resource over allocation or penalty costs are set to be assigned by user. As a result, the entire optimization parameter is an only cost variable. Also, the proposed method can be used to consider this trade-off to develop resource usage schedules effectively. Because of activity construction method alternatives are enormous number, GA has been applied to the optimization process. The algorithm was tested, evaluated and the outcomes were compared to those established by the Microsoft Project. The evaluation shows that the developed algorithm can determine suitable and balanced solutions related to the three objectives and that these solutions are much better than those determined by commercial software. The major gap of the Kaiafa and Chassiakos [22] model is that all input must be as a cost to can deal with.

Elkabalawy and Moselhi [23] proposed an integrated method for resource-constrained schedule compression under uncertainty with option of choosing an optimal solution from a set of non-dominated solutions. Fuzzy set theory (FSs) is used to model uncertainty in activity durations and costs, while GA is used to optimize project schedule. The method has four main modules; First, uncertainty and defuzzification module, to model construction activity durations and costs uncertainty by using FSs and convert fuzzy input variables into crisp values; second, scheduling module, to determine the early and late date for activities and define critical activity durations in the project. Also, to allocate required resources to their activities consequently, draw the Gantt chart to calculate and the demand resource in order to perform non-critical activity splitting depend on resource availability; third, cost calculations module, which utilize user input and scheduling module output to calculate cost for splitting, costs for resources acquiring and releasing besides the direct, indirect and delay opportunity/ penalty cost.

Splitting cost is defined by the extra cost associated with stopping the activity and later restarting it and it is calculated by the cost of one split multiplied by the number of splits, resources acquiring and releasing cost is defined by the additional cost related to hiring and firing resources, and it can be calculated by multipling the number of acquired and released resources for each period of the projects by the acquiring and releasing cost rate, Fourth, decision-support module, which utilize the weighed sum method to help project managers in selecting the most practical scenario among the produced ones. A 2D Pareto front for time, cost solutions is created for the desired alpha-cut values and project parameters where the optimum solution is chosen. A preference index for each solution is generated in the weighted sum method, whereas the best solution has the lowest preference in the minimization case. On the other hand, the best solution is the one with the highest preference in the maximization case.

Two optimization methods were supported by four main modules, the two methods were evaluated using a multi-layered comparative analysis so as to compare their outputs and assess their performance. The elitist non-dominated sorting genetic algorithm (NSGA-II) is used in first optimization method, while a dynamic weighted optimization genetic algorithm is used in second method. NSGA-II outperformed the weighted optimization method as results showed, resulting in an improved global optimum solution with less trapping of local minima. The improvements in the method help in rapid finding optimal solutions within reasonable time. Also, the improvements are expected to assist contractors in generating effective schedule compression while ensuring effective resource usage. Moreover, improvements provide the following; a multi-objective optimization within uncertainty that addresses TCT and allows for activity splitting and providing a smooth resource utilization; 2D Pareto front for project duration and cost to help managers in selecting the optimum solution; and a stand-alone automated tool may be used to schedule compression. The major gap of the method by Moazz Elkabalawy and Moselhi [23] is excluding the multi-resource constrained scheduling. Besides, all non-critical activities can be split, and excluding multiskilled strategy as well as activity splitting would help in solve resource-constrained problem.

Fini et al. [24] presented a mathematical model that achieve the optimal crew formulation of single and multi-skilled labors, with different levels of experience, in the same crew to minimize repetitive construction projects duration and optimizing workers allocation to activities by addressing learning on the crew's productivity, level of skill, and the overlapping effects of multiskilling. Also, taking into consideration on-the-job learning opportunities for both single-skilled and younger labors for example; providing on-the-job skill-learning by placing both multi-skilled and single-skilled labors in the same crew to give single-skilled labors chance to learn new skills, within the same way, for younger, trainee, and/or less experienced labors, placing both highly and less-experienced labors in the crew.

The level of labors skills will impact final product quality. Accordingly, it is usually preferred to keep a specified number of highly-experienced labors in crew to maintain the product quality. In each team, these workers also serve primarily as mentors or superintendents. The contractor shall determine the minimum number of highly-experienced labors in crew based on the previously experience and project features, taking into consideration safety issues that maybe occur in the site as each construction site has a limit of maximum number of people that can work simultaneously which be determined also by the contractor based on activity type, construction site dimensions, and existing safety precaution facilities. The optimal crew formulation for various activities included in the project is identified by utilizing a solution technique which integrates statistical analysis, constraint programming (CP), and GA. The model is suitable for the small and medium-size networks. Neglecting project cost optimization and resource-scheduling problems especially for multiskilled labors are a major gap in the model developed by Fini et al. [24].

B. Unconstrained resources

Hariga et al. [25] addressed the multi-resource leveling problem when decisions about project schedule and material procurement are taken simultaneously. The developed integrated renewable resource leveling and consumable resource lot sizing problem with allowed activity splitting (IRLLS) model aims at minimizing scheduling costs (splitting, releasing and acquiring costs) as well as material costs (ordering and holding costs). IRLLS model studies the splitting/preemption of noncritical activities as a tool to smooth renewable resources usage profile. A mixed integer linear programming model is developed, and uses noncritical activities splitting strategy in order to level the renewable resources. The developed model is solved using IBM ILOG CPLEX optimization package to reduce renewable resources smoothing costs along with consumable resources costs. A hybrid metaheuristic procedure is suggested to solve the model for large-scale and complex projects. Hybrid metaheuristic approach is developed where PSO is combined with SA. Additionally, the integrated approach led to significant reduction in total costs for low values of the releasing and acquiring costs of the renewable resources. Computational experiments performed over 240 test instances of different size, and complexity show the proposed metaheuristic approach efficiency as it produces solutions near optimal solution with average variance 1.14%.

There is inevitability of having construction managers handle project scheduling and materials lot sizing decisions simultaneously, instead of consecutively, to enhance resource leveling and reduce materials costs. Generally, the integrated approach may cause increasing in renewable resources costs but it will also cause decreasing consumable resources costs, when the latter decreasing outweighs the potential increasing in renewable resources costs. The developed model by Hariga et al. [25] was Neglecting resource-constrained problem which would be a major gap. Also, multi-mode may be added to the model to improve the resource-scheduling problem as well as resource leveling problem.

Yan et al. [6] presented an optimization model of cost for the multi-resource leveling problem without constraint of project duration. The assumption of the model that project duration can be changed but in a certain range, all resources are rare, and the relationship between project cost and the scarce resource usage fluctuations is analyzed, although there exist major limits in traditional resource leveling problem based on project duration is fixed so the solution would be by shifting noncritical activities within their start and finish time. Moreover, the model is taking into consideration five types of cost: extra hire cost, if the resource requirement is greater than resource availability, on the contrary, idle cost, if the resource availability is more than the resource requirement, indirect cost that associated with the duration, liquidated damages if the project is prolonged than the predefined duration, and the incentive fee if the project duration is shorten. These costs make the model closer to realistic construction environment, and Minimizing the sum of these five types of cost is model main objective. Excluding constrained resource problem is one of the major gaps in the developed model by Yan et al. [6]. Also, using one construction method and neglecting multi construction method strategy which will help significantly in solving the problem.

Hariga et al. [26] presented a model that integrated the TCT and resource smoothing problems by formulating mixed integer linear program (MILP) model and with assumption that activities are allowed to be split. Providing a flexible and friendly-user tool to project managers to have the ability in decision-making process related to shorten project duration and to smooth the project resources utilization are the aims of the proposed model. It was assumed that the most impact on the total cost is the direct and indirect cost and followed by smoothing resource cost and also cost of splitting. The running time computing on various created test instances showed that it is potential to schedule small- and medium-size projects with up to 16 activities optimally within a reasonable and time. The main gap in the model developed by Hariga et al. [26] is that the quality wasn't being included in tradeoff optimization. Also, the model was established with fixed resource demand rate for each activity which is impractical assumption. Another gap is to resource-constrained problem is neglected. Finally, the model is suitable for small and medium-size projects only.

Li et al. [27] studied the resource leveling problem with stochastic minimum time lags (RLP-SMTL), in which both activity durations and time lags are uncertain, strives to find a scheduling scheme to make the usage of renewable resources leveled as possible all time. For the RLP-SMTL, a simulation-based solution framework is proposed. Two metaheuristics, a bat algorithm (BA) and an evolutionary algorithm (EA), are created based on the proposed solution framework. Depend on

1,080 randomly created 100-activity instances; comprehensive computer experiments are implemented to assess the efficiency of the proposed algorithms. The findings show that EA is more effective than BA, the EA preforms better than the BA in both the timely project completion probability and the objective function's value. On the other hand, BA is more efficient than EA. Although the strategies created by the BA are marginally weaker than EA, the BA is greatly faster than the EA. CPU time took by the EA is almost twice that of the BA with the same stop criterion. The primary contribution to the field of construction engineering and management is by establishing effective and powerful metaheuristics that provides construction manager with an automated tool for resource leveling effectively within uncertainty in activity durations and time lags. Adding constrained resource problem to the model would make the model developed by Li et al. [27] more practical for practitioners especially, construction project manager which will help in solving overall resource-scheduling problem with the uncertain in activity duration and uncertain in lag as well.

Khalilzadeh [28] presented a model to level resources by using mathematical programming considering renewable and non-renewable resources for preemptive multi-mode RCPS in construction through using the exact method and the GA integrated with the solution modification. As the exact method failed to obtain the optimal solution for large-size problems, GA obtains the nearest optimal solutions within reasonable and short computational duration. Furthermore, the results showed that, GA was able to achieve optimal solutions for small-size problems. The Taguchi method was used to setting GA parameters. Additionally, the sensitivity analysis was performed of two parameters; order strength and resource factor, to study their impact on computational duration. The model aids construction project practitioners in creating a realistic and practical project schedule to better calculate the project duration and reduce fluctuations in resource utilization during the project. The major gaps of the model developed by Khalilzadeh [28] that assuming all activities can be interrupted and the activity splitting cost is neglected. Also, excluding project cost and quality could be important gaps.

C. Time-cost trade off

Kannimuthu et al. [9] developed a framework of MRCPS environment to optimize time, cost and quality by using a binary integer-programming model which is established to conduct multi-objective optimization and identify Pareto optimal solutions which aid in quantifying relationships among time, cost and quality. Also, Relaxed-Restricted Pareto filtering (RR-PARETO3) algorithm is used to determine the best compromise solutions. The success of the framework developed by Kannimuthu et al. [9] is explained through case study projects. As the results show, the best compromise solutions are determined through multi-objective optimization for predicting construction activities quality, explanation of project performance prediction for various combining of activity construction methods which are determined from realistic projects, a new mathematical model for multiobjectives optimization of time, cost and quality, presenting of new techniques for determining compromise solutions in MRCPSs. Neglecting unconstrained resource problem and excluding use multiskilling strategy to help in solving resource-constrained problem are described as a gaps of the model represented by Kannimuthu et al. [9].

T. Wang et al. [8] identified and analyzed trade-offs among project objectives; duration, cost and quality and also supported construction industry by enabling construction managers to set the highest quality to execute a construction project within predetermined budget and duration, or minimum duration for specified budget and quality or lowest cost for specified duration and quality. A quantitative research method is adopted and developed in two main steps, first, identifying variables of model decision and formulating objective functions, and second, implementation step which performs computations using GA as a multi-objective optimization engine to conduct aforementioned trade-offs, and python is used to code the model. The main gap of model developed by T. Wang et al. [8] is that considering that the project objectives are time, cost and quality only and excluding other objectives such as excluding resource-scheduling problems as important element in most construction projects.

Elmenshawy and Marzouk [29] created a model for automated schedule generation utilizing Building Information Modeling (BIM) and to solve TCT problem arising from different alternatives presented to the user. Additionally, chances associated with the interface between Primavera software and automated schedule generation model are supported. Furthermore, it permits activity data to be imported from MS Excel. Furthermore, there are a variety and diversity of solutions, each solution related to specific duration and cost based on the performance factor that reveals the crews number allocated to the activity and/or construction method. A model is created to make use the quantities from a BIM platform, produce construction activities, determine the activity duration and finally the logic sequence is applied to make relations among the activities. Then, by using NSGA-II multi-objective optimization is performed to find the most feasible and practical solutions taking into consideration project duration and cost. The researchers chose NSGA-II because it is widely used, well-known, reliable, trustworthy algorithms, and its results were tested and compared in various studies such as optimizing life cycle costs of sustainable buildings [30], solving MRCPS problems [15], and scheduling [31]. The aforementioned model is able to choose the near-optimum project scenario. At least buildings of a ground and two floors are allowed, mechanical, electrical and plumbing (MEP) activities aren't involved and only one type of slabs or columns can be made per floor which are described as major gaps for the model developed by Elmenshawy and Marzouk [29].

Sharma and Trivedi [11] presented a multimode resource-constrained time–cost–quality–safety tradeoff optimization model as well as considering limitations of resources for each construction method of activities. The model is developed using a population-based meta-heuristics approach the NSGA III. Also, Latin hypercube sampling for population initialization is used to handle premature convergence and to create well distributed initial population, analytical hierarchy process for determination quality weight of indicators and activities and fuzzy logic for determining safety parameters.

Moreover, a value path plot is developed to display of more than three objectives and a priori method is represented to select a solution from Pareto-optimal front. The aforementioned model will be helpful to project contributors in the way of increasing profit, quality and safety, while minimizing risk. Excluding uncertainty in activity duration and cost, and multiskilling strategy in solving RCPS are main gaps in the Sharma and Trivedi [11] research.

Sonmez et al. [32] presented a novel uncrashing heuristic for large-size projects which provides an advancement in time-cost optimization and able to achieve effective solutions within a reasonable CPU time. Also, a novel scheduling method is presented to efficiently reschedule of noncritical activities to reach best solutions in short and reasonable time for TCT of large-size projects. The new schedule technique can also be helpful in reducing schedule calculations of other heuristic and metaheuristic optimization approaches that is requiring repetitive rescheduling of the noncritical activities, such as cash flow optimization or resource leveling. The mixed-integer programming method which was presented by Sonmez et al. [32] is used to determine optimal solutions for the Pareto problem instances up to only 200 activities which could be major gap for this method.

Banihashemi et al. [10] presented a model to solve discrete time–cost–quality–environmental impact trade-off (TCQET) problem in construction by multi construction methods for project activities to decrease environmental impact of project execution. So, to achieve the four objectives; minimizing project duration, cost, and environmental impact as well as maximizing project quality, a multiobjective model was created. And then, the problem was designed as a single-objective by transforming the objective function to a constraint. Furthermore, to assess environmental impact Leopold matrix method was used.

Finally, to show the applicability and efficiency of the proposed model, a part of a rural water supply project was adopted as a realistic project. The results revealed that, the proposed method used in trade off the four aforementioned objectives is working efficiently, also planning and decision making in the early phases of a project to select the appropriate construction method to execute t activities will result in minimizing project duration, cost, environmental impact, and enhancing project quality. stakeholders and project managers can take into account the environment around them by calculating project activity environmental impacts in each construction method, while tracking project duration, cost, and quality objectives, and reduce the project overall adverse environmental impact as a quantifiable amount. As a result, project managers will be able to allocate the most appropriate construction method to the project activities in order to complete the project with the minimum duration, cost, and environmental impact, and with maximum quality. The main gap in the study conducted by Banihashemi et al. [10] is that absence of research methods and resources and also difficulty in assessing and calculating the four factors of time, quality, cost, and environmental impacts in each construction method for each activity.

Lin and Lai [33] developed an optimization technique to reduce project duration. The developed TCT model takes into account variable productivity which is affected by management and working environment. GA is used in optimization on MS Excel; to make the model easier for researcher and practitioner in real projects. The decision maker can maintain original budget while minimizing project duration through improving the labor productivity and shorten duration by management initiatives for example, improving processes, reducing waste, and providing incentives and training, while overcoming rework or fatigue which may be results in other optimization techniques. The study's primary contribution is its application of managerially improved labor productivity to the TCT problem. As a result, project duration can be minimized due to enhanced productivity of existing crews instead of overlapping or increasing shifts or crews' number. Also, the decision maker will use the proposed technique to shorten the project duration and reduce liquidated damages risk when performing TCT problem under predetermined budget. The major gap of the technique developed by Lin and Lai [33] that it couldn't ascertain how long the duration of project can be applied into the model because of the uniqueness of a construction project. Also, schedulers with different experience will lead to variation in appraisal of the improvement factor. Moreover, excluding multiskilling strategy in improving productivity could be defined as a gap.

Mrad et al. [13] developed a simulation-based integer linear programming (LP) tool to help project managers, in evaluating risks that associated with the profitability and feasibility of the projects in the framework of a stochastic discrete TCQT problem through integrating the integer linear programming with MCS tool, which allows to evaluate risks related to duration, cost and also quality. In the project management area, the aforementioned approach can support decision makers to choose the best and most valuable project among many potential alternatives based on the risks related to their cost, duration, and quality. The aforementioned approach is capable of evaluating impact of the stochastic behavior of activity durations and activities' quality on the entire project cost, duration, and quality. Moreover, this approach is very hopeful for determining a practical solution for realistic projects because of the simplicity and the reduction in duration required to the computation of large size networks. The costs of the activities are proposed to be deterministic values. Also, the construction method quality of the activity is a function of its cost which could be a major gaps of the model developed by Mrad et al. [13].

Togan and Eirgash [34] presented a novel initial population approach for improving the optimal set of time-cost alternatives quality. It incorporates a specified number of solutions into the single objective TCT problem to the initial population of teaching learning-based algorithm, which is used as an optimizer for the multi-objective optimization of TCT. Therefore, it strives to reduce the initial population randomness and lessening the effort of searching to find the optimal set in the search space. The proposed methodology is put to test on a series of benchmark problems and the results obtained are compared with other various modern metaheuristic optimization approaches such as; GA, PSO, SA, shuffled frog leaping optimization, and ant colony optimization (ACO). Additionally to these methods, electimize algorithm, differential evolution algorithm, and branch and bound algorithm. As a result, the aforementioned approach can produce promising solutions powerful and effective like other methods adopted for simultaneous optimization of TCT problem. Also, with a less searching process, it can speed up the optimization process and improve the outcomes. The main gap in Togan and Eirgash [34] model is summarized as the approach can't identify the global optima. On the contrary, it can identify the acceptable solutions near-optimum with deviation 7% from the optimal.

Toğan and Eirgash [35] presented a multi-objective optimization model based on the Teaching-Learning Based Optimization (TLBO) and incorporated with the Modified Adaptive Weight Approach (MAWA) which titled as MAWA-TLBO. Weighted approach is used to convert a multiple objective to single objective optimization, and the weights are adjusted in an adaptive manner. It indicates that their values variation based on population performance. The model has been developed to solve the discrete TCT problems, so as to optimize project total duration and total cost simultaneously and to find a set of Pareto front solutions. The main Contribution of model is related to its ability in finding the Pareto front for the small and medium-scale realistic problems. Additionally, this study contributes significantly in improving the limitations of solving more complex and large scale discrete TCT problems using MAWA approach. The results obtained from using MAWA-TLBO optimization are verified by comparing with results obtained from using PSO, GA, and ACO. Accordingly, comparative results obviously demonstrate practicability and competence of the TLBO on solving TCT problems in construction project management. Moreover, the results show that the TLBO has a significantly possible for solving concurrent optimization of large TCT problems e.g., 63-activity project. Additionally, the simplicity of MAWA-TLBO algorithm can be consider as strong point of it. The main gap in Toğan and Eirgash [35] mode is that was suitable for only medium-sized real-life problems. Also, it excluded other important objectives in projects such as quality, safety and resource-scheduling problems.

Agdas et al. [36] created a novel approach to address TCT large-size problems in construction by GA which can solve realistic TCT problems with high accuracy, and consuming little and reasonable processing time. It was formerly able to accurately solve enormous benchmark networks with up to 630 variables with deviation approximate <3% regularly through utilizing personal computer in less than 10 min. The developed approach may also be utilized to handle bigger networks with up to 6,300 variables with reasonable accuracy with deviation about 7% at longer processing times. The gaps of the approach introduced Agdas et al. [36] are that excluding the resource-scheduling problems. Also, it didn't take into consider the project quality.

Kosztyán and Szalkai [37] proposed an algorithm and a novel matrix-based project planning method to model resource-constrained hybrid TCQT problems (RC-HTQCTPs) and determine least amount of time-consuming, minimum project cost scenarios and project structures within the defined restrictions. The algorithm is efficient and quick as it supports the hybrid project management (HPM) approach which merges methods (e.g., TCT and TCQT methods) from traditional project management with structuring and scoring techniques from agile project management. In addition, based on specified preferences regarding factors such as time and cost, the algorithm also is able obtain an optimal solution. The proposed exact algorithm and developed matrix-based method might be important and necessary parts in a project expert system that supports decision-making, especially in complex and large-size cases, and flexible projects. Consequently, the method may be used to combine the agile and traditional approaches. So, RC-HTQCTPs were studied to extend the traditional TCQT model by based on the agile approach. Neglecting resource leveling problem and MRCPS are main gaps of method developed by Kosztyán and Szalkai [37].

Luong et al. [38] developed an alternative differential evolution-based methodology to solve the construction TCQT problems by obtaining an optimal set of activities' construction methods corresponding to achieve project duration at minimum, and project cost and quality at maximum. Opposition-based Multiple Objective Differential Evolution (OMODE) is proposed as novel multi-objective optimization algorithm that uses an opposition-based learning technique to enhance significantly initial population diversity and create potential candidates at the algorithm beginning. However, to balance OMODE diversity and convergence Opposition-Based Learning (OBL) is applied through the whole evolution process. OMODE showed better diversity features, produced better compromise solutions, and attained a higher level of satisfaction than the broadly used evolutionary algorithms; multiple objective differential evolution (MODE), PSO, and NSGA. The Pareto front created by OMODE provides construction-project decision makers by information that aids them in determining the optimal tradeoff among project duration, cost, and quality as three main and important project objectives. The resource-scheduling problems need to be integrated to the developed model by Luong et al. [38] to provide overall view to the project which would be an significant improvement.

Nemati-lafmejani et al. [39] introduced a model can deal with Contractor Selection (CS) problem as well as MRCPS concurrently, as an integrated bi-objective optimization model. The main purpose of the model is to decrease the project total cost, and minimize the project duration, concurrently. Also, calculate activities' dates, and allocate suitable contractors to corresponding activities in a coordinated way. To solve the integrated MRCPS-CS, two multi-objective meta-heuristic algorithms are used; Multi-Objective PSO (MOPSO) and NSGA-II. Moreover, to calibrate parameters of MOPSO and NSGA-II algorithms Taguchi method was used. And then, both parameter-tuned algorithms were used to solve 30 randomly created different-scale test problems. Quality isn't included in the model presented by Nemati-lafmejani et al. [39] when solving the problem of constrained resources. Also, it was neglected the problem of unconstrained resource, besides multiskilling strategy.

Bettemir and Birgönül [40] introduced minimum cost-slope method based network analysis algorithm (NAA) to solve discrete TCT problem. To easier the activities relationships, the proposed method is developed for Activity-on-Node (AoN) type networks. The aforementioned algorithm is tested in regards of ability of finding the global optimum and its rate of convergence. The results of test showed that the algorithm converges to find optimum or near optimum solutions significantly quick. Additionally the method delivers better solutions than heuristic algorithms. Moreover, adapting of NAA for the AoN opens the door to develop new hybrid meta-heuristic algorithms by integrating it with meta-heuristic algorithms. As a result, the proposed NAA is an appropriate optimization method to solve discrete TCT problem. The scope of model introduced by Bettemir and Birgönül [40] is neglecting multiskilling and its effect on leveling resource could be defined as a gap. Moreover, project duration and quality aren't taken into consideration.

IV. Content Analysis

A. Resource-scheduling problems

Constrained resources (resource allocation) and unconstrained resources are typically the two models used for resource scheduling (resource leveling). So, the previous research work related to resource-scheduling problems will be classified into two categories: constrained resource and unconstrained resource.

A.1 Constrained resources problem

Constrained resources problem or RCPS problem is a significant and complex problem in projects especially in construction projects. This is due to the following reasons; (1) the analysis of the problem has several conflicted objectives (minimum prolonged project duration and satisfy resource constraints, (2) The size of the problem grows exponentially with the number of project activities, resources, and alternative activity construction methods, (3) finding the optimal activity crew and the right activity date is necessary to ensure that resources are used effectively [22]. Neglecting this problem may be lead to serious issues by delaying project schedule which will result in liquated damage or delay penalty. Thus, RCPS has received great attention from researchers and practitioners to solve the problem by using different construction methods for activities [15], [19], [22], developing algorithms [2], [16]–[18], [23] or using multiskilling labors [20], [24].

A.2 Unconstrained resources problem

Unconstrained resources problem is attempting to balance resource use across the whole project life cycle [6], in different word, achieving better resource distribution (histogram) through the project execution especially, labors and equipment. The major issues result from unleveled resources; shortage, idle time and hiring and firing, which lead to extra costs, delaying project and sometimes negative social effects [28]. So, some researchers keen on solving this problem [6], [25]–[28].

B. Time-cost trade off problem

Past few decades, project objectives trade-off optimization problem popularity has grown among researcher and practitioners [11]. Time-cost trade off problem is one of these optimization problems which strives to reduce project duration with minimum possible cost by using different construction methods for each activity, so it is meanly depend on different available construction methods. The development in this problem is achieved by developing new algorithms for optimization [29], [32], [34]–[38], adding new dimension(s) to trade off [8], [10], or developing new techniques [13], [33], [40] merging this problem with another [9], [11], [39].

V. Conclusion and OPPORTUNITIES Future Research

This comprehensive review aimed to study TCT and RSPs literature in order to conduct detailed and comprehensive knowledge related TCT and RSPs in construction, study the link between two areas of research, and to facilitate future studies. This review-based study in TCT and RSPs used a holistic approach in searching for publications and in making detailed qualitative discussion. 305 journal articles that are published since 2015 were chosen as a review sample. Influential journals that have been publishing research outputs TCT and RSPs include but not limited to Engineering, Construction and Architectural Management, Journal of Construction Engineering and Management, Automation in Construction and KSCE Journal of Civil Engineering, as at least Q4 journals are acceptable in this review. A state of art review of 30 articles is adopted, and summarized the mainstream research topics in TCT and RSPs, and simultaneously to identify the research contributions and comments. As shown in Fig. 1, the flow chart that depicts the adopted methodology for the review. The opportunities for future research can be deduced from the content analysis and it can be in resource management area with incorporating time-cost trade-off. Another possible area of research would be to incorporate resource management with both constrained and unconstrained to BIM to increase productivity and efficiency and also decreasing related costs when utilizing resources.

After analyzing the content of the selected articles, the biggest knowledge contributions and gaps were given. Consequently, Opportunities for Future Research were indicated as following. There is big gap in optimizing project duration and cost with taken into consideration RSPs (both constrained and unconstrained resources). Another opportunity is using multiskilling strategy as major element when dealing with RSPs to help in reducing project duration tremendously. Additional potential opportunity is using BIM when solving RSPs and safety to visualize the site area which could help in reducing safety problems. Moreover, incorporating TCT with quality and multi-mode RSPs to produce model aims to TCQT with MRCPS problems which simulate the real environment of the construction project. Further opportunity is using uncertain in activity duration as well as uncertain in activity cost in solving MRCPS problem. In addition to, a bigger attention should be given to research of incorporating safety when dealing with RSPs. Also, incorporating sustainability with TCT should be given an attention. Furthermore, a new approach for solving large projects in RSPs is needed to be developed. Finally, this review-based study in TCT and RSPs was limited to the review sample and following the next criteria. Firstly, journal articles are employed and also academic publications were gotten more focus. Conference proceedings and trade magazines were excluded. Secondly, articles published in English were only included in the review sample.

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