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Research Article

Resource Unconstrained and Constrained Project Scheduling Problems and Practices in a Multiproject Environment

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Construction companies execute many projects simultaneously. In such situations, the performance of one project may influence the others positively or negatively. Construction professionals face difficulties in managing multiple projects in limited resource situations. The purpose of this study is to identify the problems in multiproject scheduling from the practitioner's perspective and to discover current practices under resource unconstrained and constrained settings. The specific objectives are (1) determining the most challenging issues being faced in handling multiproject environment, (2) enumerating the practices adopted in the industry, and finally (3) identifying the practitioners' perceptions on the multiproject scheduling aspects such as network modeling approaches; activity execution modes; concept of sharing, dedicating, and substituting resources; centralized and decentralized decision-making models; solution approaches; and tools and techniques. An online questionnaire survey was conducted to address the objectives above. The top challenging issues in managing multiproject environment are identified. Factor analysis identified the factors by grouping the variables (a) decision-related, (b) project environment-related, (c) project management-related, and (d) organization-related factors. Resource-unconstrained situation mainly faces the issue of underutilization and wastage of resources leading to lower profit realization. The following findings were identified to overcome the unconstrained resource situation such as identifying the work front, adopting pull planning approach, creating a common resource pool, and allotting it on a rental basis. On the contrary, resource-constrained situation faces the issues of prioritization of resources, coordination, communication, collaboration, quality issues, and rework. The findings suggest the strategies such as top-up via subcontracting, proactive pull planning, introducing buffers, training the culture of the organization towards better communication, coordination, and collaboration, to improve the reliability of achieving baseline project performances. Various multiproject aspects suggested for effective management. The identified problems, practices, and various multiproject aspects are expected to contribute better management of multiproject resource unconstrained and constrained project scheduling.

1. Introduction

Organizations in the construction industry execute a portfolio of projects under tight time and resource constraints [1]. However, construction management research is dominated by a single-project model [2]. The ability to manage multiple projects in the competitive environment becomes an essential competence [3]. The projects may vary in size, importance, and the skill required at various stages and still use the same pool of resources [4]. Multiproject scheduling is a fundamental problem for enterprises to reasonably allocate the limited resources to optimize the performance of the project [5]. Herroelen [6] states that even a small improvement in multiproject management will yield a significant benefit to the project management field. More than 90% of all international projects are executed in a multiproject environment [7], and 84% of firms handle such multiple projects in parallel [8]. Therefore, the identification of challenging issues in the multiproject environment is highly beneficial.

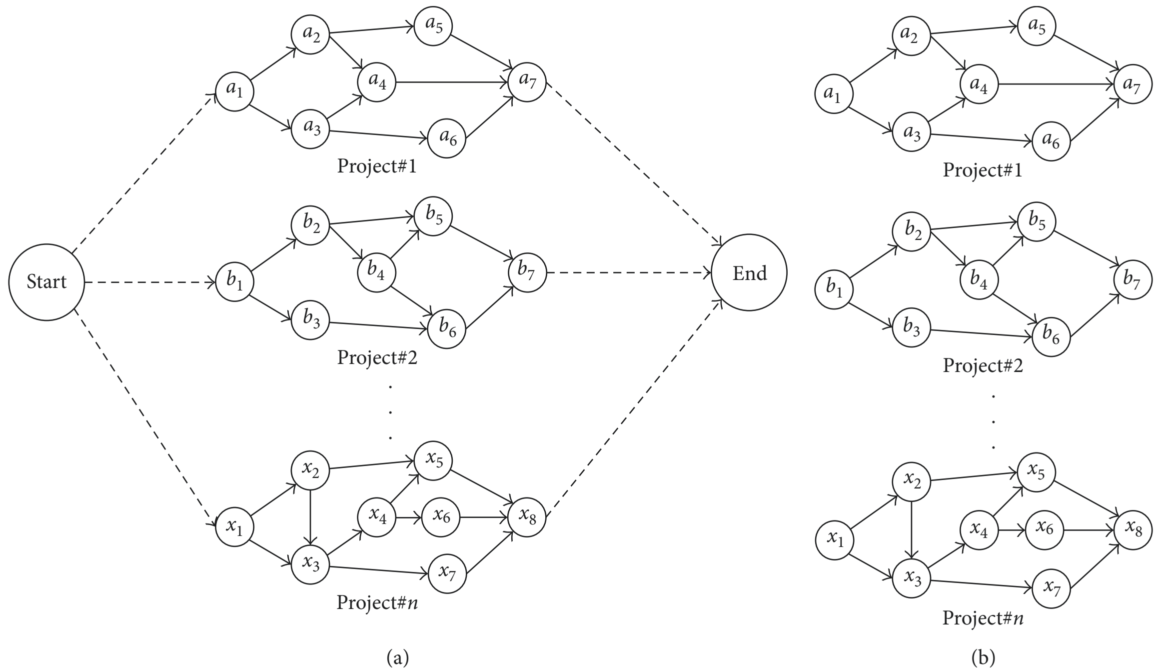

Figure 1: Network modeling approaches in the multiproject environment (MPE). (a) Single-project approach. (b) Multiproject approach.

The resource-unconstrained project scheduling approach presents a solution to time-constrained projects. However, the realistic situation involves optimizing multiple conflicting objectives in a resource-constrained project scheduling environment. The resource-constrained project scheduling problem (RCPSP) presents an extension to the standard Critical Path Method (CPM) and Program Evaluation and Review Techniques (PERT) by including the availability of resources [9]. The resource-constrained multiproject scheduling problem (RCMPSP) [10] and multimode resource-constrained multiproject scheduling problem (MRCMPSP) [11, 12] are the extensions of RCPSPs. The identification of resource unconstrained and constrained project scheduling problems and practices may lead to better management of the multiproject environment.

Yang and Sum [13] proposed the dual-level management structure for managing multiple projects. Project managers are responsible for operating the project activities, whereas upper-level managers work at a more tactical level and are in charge of all the projects and project managers. Traditionally, the RCMPSPs are solved with the assumption of centralized decision making in which the resource allocation and scheduling decisions were made centrally in an integrated manner [14]. Centralized planning model requires complete information of all the projects so that a satisfactory plan can be obtained more quickly. Coordination and communication channels should be in a proactive mode for the effective implementation of the centralized model. In practice, the resource allocation and scheduling functions are performed in a decentralized manner. The decentralized model has advantages in coordination and fairness among multiple projects and is more realistic [15, 16].

This study aims to identify the main challenges in multiproject scheduling from the practitioner's perspective and to discover current practices in resource unconstrained and constrained settings. The remainder of the paper is organized as follows. Section 2 describes the relevant literature specific to challenges in managing the multiproject environment: resource unconstrained and constrained situations. Section 3 outlines the research methodology to achieve the objectives above, and Section 4 discusses the results of challenges in multiproject environment: resource unconstrained and constrained multiproject problems and practices, and various aspects of multiproject scheduling. Finally, Section 5 describes the concluding remarks and possible future research directions.

2. Studies on Multiproject Scheduling Environment

Two main approaches are followed in the network modeling of multiproject scheduling: single-project approach [17, 18]; and multiproject approach [19] (Figure 1). In single-project approach, all projects are considered together to form a single critical path with the objective to minimize the total makespan (TMS). The single-project approach has several drawbacks: (i) it is less realistic and implicitly assumes equal delay penalties and (ii) in many practical situations, each project has its manager who is interested in achieving the individual project's performances [19]. In, multiproject approach, each project is handled independently with the objective to minimize the average project delay (APD).

In multiproject scheduling, the projects are prioritized based on project selection priority rule [10]. Traditionally, all projects are controlled by one decision maker. Nowadays,

Table 1: Challenges in a multiproject environment (MPE).

	Challenges	Reference(s)
1	Division and assignment of resources/resource allocation	[2, 4, 9, 25–27]
2	Organizational culture	[26, 27]
3	Management support	[4]
4	Prioritization/project selection	[4, 25]
5	Real-time monitoring and proactive decision making	[23]
6	Capacity (resource)	[7, 24]
7	Complexity (multiple interfaces between the projects)	[2, 7]
8	Conflict (people, system, and firm issues)	[7]
9	Commitment	[4, 7, 24]
10	Context (regulative, normative, and cognitive)	[7, 9, 24]
11	Communication	[4, 25]
12	Coordination	[24]
13	Volatile economic environment	[2]
14	Dynamic nature	[24]
15	Duration and resources (cascade effect)	[24]
16	Competencies of project manager	[4, 25–27]
17	Project manager assignment	[27]
18	Project management processes (information sharing)	[25, 27]

due to active intrafirm and interfirm collaborations, multiproject management has entered a new environment where different self-interested decision makers control the projects. It seems that centralized RCMPSP is no more valid for the current situation. Under this background, the decentralized RCMPSP is formally proposed [20, 21]. The attributes of decentralized/distributed (multiagent) multiproject scheduling problem are the decision maker, the decision mode, and the coordination approach. Coordination is achieved through centrally imposed solutions, contracts, auction, argumentation, and mediated single-text negotiations [22]. The applicability of decision-making models needs to be evaluated from the practitioner's perspective.

2.1. Challenges in a Multiproject Environment. In a multiproject environment, organizations expect (1) structured approach for making "go" or "no-go" decisions during project selection, (2) looking for an optimum program schedule that incorporates significant decision variables of the company, project delivery system, individual project objectives, driven factor, and priority, (3) dealing with uncertainties, and (4) real-time monitoring of the projects [23–27]. Table 1 identifies the common challenges in the multiproject environment (MPE).

2.2. Resource-Unconstrained Multiproject Scheduling. Most widely used CPM and PERT techniques deal with time aspect only [28]. It has severe limitations: (1) assumes unlimited resources and (2) applies to only one project at a time [29–31]. Besides, Fondahl [32] introduced the precedence diagramming method (PDM) to represent a realistic relationship between the activities. However, the inability to perform resource scheduling is the main drawback of the network scheduling methods. CPM, PERT, and PDM methods fail to synchronize activity planning and resource planning seamlessly. Neither Gantt nor CPM, PERT, and PDM address the decisions required in multiproject setting [33]. Although these models are still applicable in some real-world projects, a deterministic assumption and limited to single-project application make it inaccurate for multiproject environments. In multiproject environment, resources are constrained, but the aforementioned methods did not cover this situation. Hence, the resource-constrained multiproject scheduling consideration is essential [34].

2.3. Resource-Constrained Multiproject Scheduling. Typically, multiple projects share common resource pools whose capacities are not sufficient to support all project activities at the same time, leading to the resource-constrained multiproject scheduling problem (RCMPSP) and multimode resource-constrained multiproject scheduling problem (MRCMPSP) [35]. MRCMPSP is the extension of RCMPSP where each activity possesses different execution modes. The activities can be executed with the several combinations of modes using various construction methods, materials, crew size, and overtime policy. Under this situation, each combination will have different project performances regarding time, cost, and quality [5]. Although RCMPSP and MRCMPSP play a vital role in project management, there are not many fruits on the topic. The main reason is due to high complexity, which is affected by many factors, such as the vast solution space, the intensity contending for resources, conflicting objectives, the interproject dependency and priority, and the high level of uncertainty [36, 37].

The multiproject intention is to prioritize the project's activities to optimize an objective function without violating both intraproject and interproject resource constraints. Choosing between alternative optima makes the changes in the scheduling easier and faster than rescheduling [38]. At the tactical planning level, managers face the crucial decisions such as allocating resources among various projects, establishing due dates and other milestones for bidding proposals, and determining the optimal trade-off between the absorption of resources and the duration and the costs associated with alternative "modes" of performing each activity. It should be noticed that such decisions have an enormous impact on the whole performance of a company [39].

Kim and Leachman [40] proposed linear programming to optimize the trade-offs of lateness costs among projects. Deckro et al. [41] offered the integer programming with decomposition approach for solving the multiproject, resource-constrained scheduling problem. Mittal and Kanda [42] considered integer linear programming model for interproject resource transfers. Krüger and Scholl [43] proposed a framework for resource transfers considering (i) managerial approaches—transfer neglecting approach, resource reducing approach, and resource using approach;

(ii) types of resource transfers—time, abstraction, and support. Confessore et al. [20] developed an iterative combinatorial auction mechanism for the agent coordination using dynamic programming. Liu and Wang [44] established a profit optimization model for multiproject scheduling problems considering cash flow and financial requirements. Exact methods suffer from large problems due to the combinatorial explosion phenomenon [45]. It is not computationally tractable for any real-life problem size, rendering them impractical [46, 47].

Another alternative is the approximate methods which can be divided into priority rule-based heuristics, classical metaheuristics, nonstandard metaheuristics such as agent-based, and different heuristics [48]. Kurtulus and Davis [49] proposed multiproject scheduling rules to minimize total project delay: shortest activity of shortest project (SASP), largest activity of largest project (LALP), activity with highest resource demand first (MAXRD), activity with maximum slack first (MAXSLK), activity with lowest precedent work, activity with highest precedent work. Lova and Tormos [8] analyzed the effect of priority rules, minimum late finish time (MINLFT), minimum slack (MINSLK), maximum total work content (MAXTWK), and SASP or first come first serve (FCFS) with network modeling approaches, and found that MINLFT with multiproject approach performed the best. MINLFT produces most substantial different best schedules almost equal to those produced by MINSLK and minimum late start time (MINLST) [50]. The maximum total work content (MAXTWK) can be more efficient with the bounds of resource usage in multiproject schedules [51]. Suresh et al. [10] analyzed the two-phase priority rules, that is, project priority rules and activity priority rules to maximize the net present value (NPV) under resource transfer times. Heuristic methods have been extensively used in practice [52]. However, heuristic models are problem-dependent, implies that the rules specific to a model cannot be applied equally to all problems [53], and do not guarantee an optimal solution.

The various neighborhood and population-based metaheuristics provide a generalized and robust approach to offset the limitations imposed by the exact and rule-based heuristics. Chen and Shahandashti [54] utilized simulated annealing (SA) for optimizing multiproject linear scheduling. Suresh et al. [10] presented genetic algorithm (GA) approach to the multiproject scheduling problem with resource transfer times. Tran et al. [55] introduced a fuzzy clustering chaotic-based differential evolution (DE) for solving multiple resources leveling in the multiple projects scheduling. Rokou et al. [56] implemented the GA to deal with classification and prioritization of the projects and ant colony optimization (ACO) to perform the activity list optimization for each project. Deng et al. [57] applied particle swarm optimization (PSO) to search the optimal schedule for the RCMPSP. A nondominated sorting genetic algorithm II (NSGA-II) is proposed to obtain optimal trade-offs between different projects objectives [5]. Abido and Elazouni [58] introduced strength Pareto evolutionary algorithm (SPEA) to minimize the financing costs, duration of a group of projects, and the required credit. Even though many approaches have been proposed to handle the multiproject environment, learning from practices still required to consider the integrated behavior of various multiproject modeling aspects. This study is proposed to identify the multiproject scheduling problems and practices with resource unconstrained and constrained settings from the practitioner's perspective.

3. Research Methodology

A questionnaire survey is adopted to identify resource unconstrained and constrained multiproject scheduling problems and practices. Constructivist ontology and positivist epistemology have been adopted as research philosophy along with quantitative and qualitative research methodology, survey research design, and questionnaire-based research method. A questionnaire-based study is applied predominately for descriptive research, seeking to investigate and analyze research problems [59].

3.1. Design of the Questionnaire Survey. The survey is done through an email-based questionnaire. The respondent contact information is obtained through LinkedIn. The survey consists of five parts: first, challenges faced in managing multiproject environment; second, resource-unconstrained problems and practices; third, resource-constrained problems and practices; fourth, various multiproject environment aspects such as network modeling approaches, decision-making models, activity execution modes, concepts of sharing, dedicating, and substituting resources, solution methods, and tools and techniques; and in the last part, the respondent demographics are collected. The first part of the survey consists of ordinal data related to importance scale 1 to 5 (Likert scale). Five-point Likert scale appears to be less confusing and increases the response rate. Previous authors have used a similar scale for the construction management research [26, 60]. In the second and third parts of the survey, the subjective opinions are extracted for the resource unconstrained and constrained situations, and each has three subitems. The fourth part of the survey involves nominal data and subjective opinions. The final part contains information such as respondent designation, years of experience, the category of stakeholder, and region.

3.2. Characteristics of Respondents. The pilot study was conducted to refine the survey questions from the three industry experts. The responses are collected from sample units project engineer, planning engineer, project manager, construction manager, and general manager. A total of 90 valid responses were received. The responses were received from 17 different countries: India, UAE, Oman, Saudi Arabia, Qatar, South Africa, USA, UK, Malaysia, Australia, Iran, Singapore, Peru, Bahrain, Russia, Sri Lanka, and Pakistan. The distribution and characteristics of the respondents were tabulated in Table 2.

Table 2: Demographics of respondents.

Demography	Project engineer	Planning engineer	Project manager	Construction manager	General manager	Total
Experience						
<5 years	15	10	2	0	0	27
5–10 years	1	8	10	8	0	27
>10 years	1	3	15	8	9	36
Stakeholder						
Client	0	2	1	1	5	9
Project management consultant	5	5	8	3	1	22
Main contractor	11	12	16	12	2	53
Subcontractor	1	2	2	0	1	6
Region						
India	12	8	8	7	5	40
UAE	0	2	3	3	0	8
Oman	0	3	1	3	0	7
Saudi Arabia	0	1	3	0	2	6
Qatar	2	2	1	0	0	5
Others (South Africa, USA, UK, Malaysia, Australia, Iran, Singapore, Peru, Bahrain, Russia, Sri Lanka, and Pakistan)	3	5	11	3	2	24
Total	17	21	27	16	9	90

3.3. Method of Data Analysis. The study was analyzed using SPSS V.24. The method of data analysis was as follows:

(1) Many previous researchers employed a relative importance index to rank the variables [60, 61]. The respondents are divided into two categories: (a) client and project management consultant (PMC) who monitors the project, and (b) main contractor and subcontractor who execute the project. The overall ranking is calculated from the combination of all stakeholders.

$$\text{Relative importance index (RII)} = \frac{\sum W}{A * N}, \quad (1)$$

where W is the weight given to each variable by the respondents, which ranges from 1 (least important), 2 (fairly important), 3 (important), 4 (very important), to 5 (most important); A is the highest weight of variable (i.e., 5); and N is the total number of respondents.

Spearman rank correlation coefficient is applied to measure the strength of the monotonic relationship between pairs of variables that influence the performance of multiproject environment. Correlation coefficients 0–0.19, 0.2–0.39, 0.4–0.59, 0.6–0.79, and 0.8–1 are considered to very weak, weak, moderate, strong, and very strong relationship, respectively, between the variables [62].

Kruskal–Wallis test is a nonparametric test alternative to one-way ANOVA for testing whether samples originate from the same distribution. The authors check the distribution between the stakeholder categories such as (a) client and project management consultant, and (b) main contractor and subcontractor.

Null hypothesis H0: significant difference does not exist in the distribution of multiproject environment variables among the stakeholder category.

Alternate hypothesis H1: significant difference exists in the distribution of multiproject environment variables among the stakeholder category.

(2) Factor analysis is used to identify the common correlating variables to form a few underlying factors. Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of Sphericity are conducted to evaluate the adequacy of sample data. Initially, the eigenvalue is set to greater than 1 for extracting the factors. Once it is identified, then factor extraction limit is assigned. Orthogonal varimax is assigned to interpret the variables. Finally, the reliability (Cronbach alpha) test is conducted for each factor and all the variables [62].

(3) Chi-square goodness of fit is employed to find out if there is a statistically significant difference between an observed set of frequencies and an expected set of frequencies of various aspects of the multiproject environment: network modeling approaches, activity execution modes, decision-making models, and solutions methods.

Null hypothesis H0: significant difference does not exist between observed and expected frequencies of multiproject environment aspects.

Alternate hypothesis H1: significant difference exists between observed and expected frequencies of multiproject environment aspects.

(4) Qualitative analysis: examining each line of data and then defining actions within (open), making connections between a category and its subcategory (axial), identifying the frequently reappeared core variables (selective). The following questions are addressed: (a) what can be learned from resource unconstrained and constrained situations? and (b) how various resource-constrained multiproject scheduling aspects are perceived?

Table 3: Ranking of challenges in managing the multiproject environment (MPE).

Variables	Client and project management consultant Rank (RII)	Main contractor and subcontractor Rank (RII)	Overall ranking Rank (RII)
1. Division and assignment of resources/resource allocation	7 (0.813)	1 (0.881)	2 (0.858)
2. Organizational culture	12 (0.690)	10 (0.753)	12 (0.731)
3. Management support	2 (0.845)	9 (0.776)	7 (0.800)
4. Prioritization/project selection	8 (0.787)	12 (0.742)	11 (0.758)
5. Real-time monitoring and proactive decision making	5 (0.832)	2 (0.878)	1 (0.862)
6. Capacity	13 (0.690)	13 (0.692)	13 (0.691)
7. Complexity	14 (0.690)	14 (0.681)	14 (0.684)
8. Conflict	18 (0.587)	15 (0.671)	15 (0.642)
9. Commitment	9 (0.781)	11 (0.753)	10 (0.762)
10. Context	15 (0.639)	18 (0.614)	18 (0.622)
11. Communication	6 (0.832)	5 (0.854)	5 (0.847)
12. Coordination	4 (0.839)	3 (0.858)	4 (0.851)
13. Volatile economic environment	17 (0.606)	16 (0.651)	17 (0.636)
14. Dynamic nature	16 (0.619)	17 (0.651)	16 (0.640)
15. Duration and resources (cascade effect)	10 (0.781)	8 (0.790)	9 (0.787)
16. Competencies of project manager	3 (0.845)	6 (0.844)	6 (0.844)
17. Project manager assignment	11 (0.768)	7 (0.803)	8 (0.791)
18. Project management processes (information sharing)	1 (0.852)	4 (0.858)	3 (0.856)

4. Results and Discussion

4.1. Ranking of Challenges in the Multiproject Environment (MPE). The relative importance index and ranking were calculated for each variable under two categories of stakeholders (Table 3). The top ranking challenges based on Client and PMC are project management processes (information sharing), management support, competencies of project manager, coordination, real-time monitoring and proactive decision making, and communication. The top ranking challenges based on main contractor and subcontractor are division and assignment of resources/resource allocation, real-time monitoring and proactive decision making, coordination, project management processes (information sharing), communication, and competencies of project manager. The five variables are shared among the two categories of stakeholders, whereas the final ranking considers the combined effect of all respondents that influence the performance of multiproject environment: (1) real-time monitoring and proactive decision making, (2) division and assignment of resources/resource allocation, (3) project management processes (information sharing), (4) coordination, (5) communication, and (6) competencies of project manager (Table 3).

Kruskal–Wallis test was applied to check whether a significant difference exists among the stakeholder's responses on the variables. The respondents were grouped into two categories: client-side (client and project management consultant) and contractor-side (main contractor and subcontractor). Statistically, a significant difference exists among the stakeholder categories only for the variables division and assignment of resources/resource allocation and management support. Management support variable is located in the seventh position considering the overall ranking, whereas a significant difference does not exist for the remaining 16 variables (Table 4).

The degree of correlation between the variables that influence the performance of multiproject environment was evaluated among one-third of the variables. Real-time monitoring and proactive decision making are moderately correlated with coordination and communication. Project management processes (information sharing) are also moderately correlated with competencies of project manager, coordination, and communication. A moderate correlation exists between the coordination and communication variables. However, the other relations between the variables are found to be weak and very weak (Figure 2). Coordination among project managers of different projects is paramount essential to achieve the efficient use of limited resources in the multiproject situation. Coordination is critical at the lower level to divide and assign the resources to meet operational efficiency. Coordination is also essential at the higher level for portfolio efficiency. The efficiency of a portfolio depends on individual projects' operational capabilities. For that, project manager's competency is the key.

4.2. Factor Analysis. The variables mentioned in Table 3 were considered for the factor analysis. The subject to item ratio was found to be 5 : 1 [63, 64]. KMO-test value of 0.824 confirmed the measure of sampling adequacy with the statistical significance of Bartlett's test of Sphericity. There are four factors recognized with the eigenvalue greater than 1. Scree plot also suggests the four components (Figure 3) [62]. Prioritization/project selection variable was removed

Table 4: Kruskal–Wallis test for checking the differences between client-side and contractor-side.

Result	Summary	
	Variable	χ^2 (1, N = 90)
Significant difference exists	1. Division and assignment of resources/resource allocation	5.108, $p < 0.05$
	3. Management support	4.303, $p < 0.05$
Significant difference does not exists	2. Organizational culture	3.565, $p > 0.05$
	4. Prioritization/project selection	1.573, $p > 0.05$
	5. Real-time monitoring and proactive decision making	1.425, $p > 0.05$
	6. Capacity	0.065, $p > 0.05$
	7. Complexity	0.003, $p > 0.05$
	8. Conflict	3.495, $p > 0.05$
	9. Commitment	0.499, $p > 0.05$
	10. Context	0.051, $p > 0.05$
	11. Communication	0.379, $p > 0.05$
	12. Coordination	0.674, $p > 0.05$
	13. Volatile economic environment	1.107, $p > 0.05$
	14. Dynamic nature	0.987, $p > 0.05$
	15. Duration and resources (cascade effect)	0.007, $p > 0.05$
	16. Competencies of project manager	0.039, $p > 0.05$
	17. Project manager assignment	0.911, $p > 0.05$
	18. Project management processes (information sharing)	0.057, $p > 0.05$

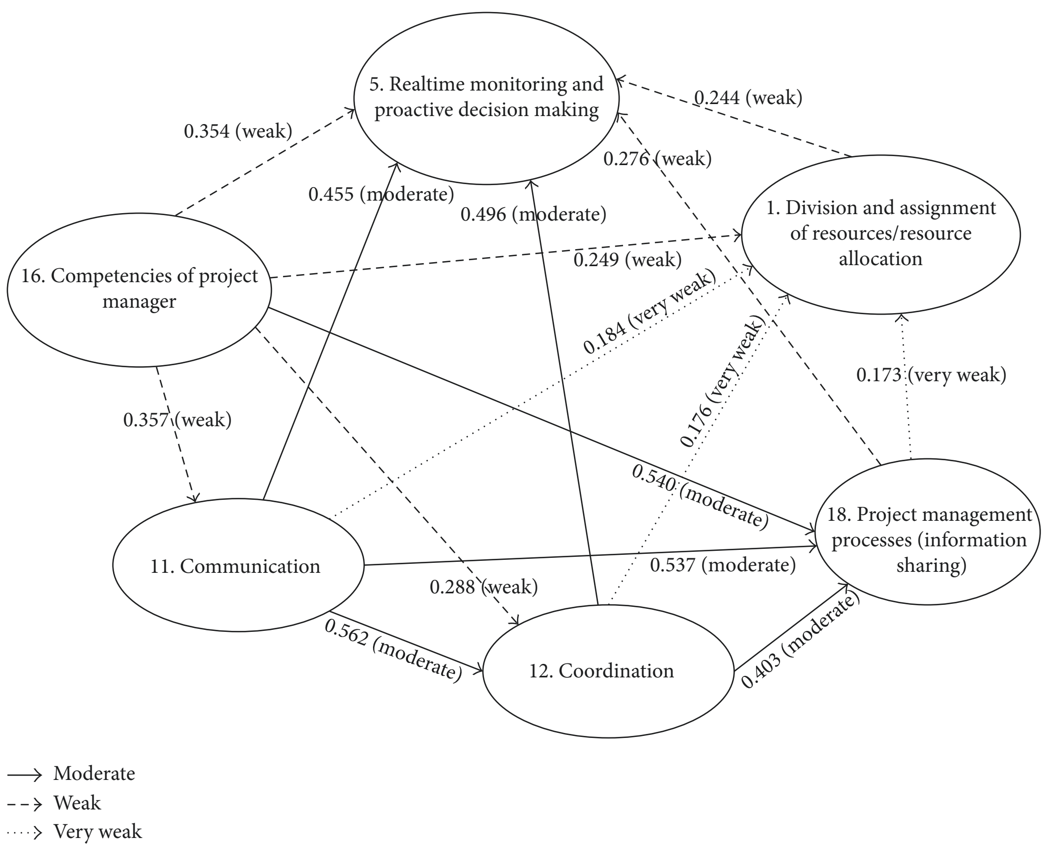

Figure 2: Spearman's rank correlation relations among the top six variables.

during the factor extraction. Factor 1 explains the total variance of 17.911% and contains six variables (Table 5). In Table 6, factor 1 variables have the Pearson correlation coefficient values between 0.284 and 0.575. The variables communication, coordination, conflict, real-time monitoring and proactive decision making, complexity, and capacity

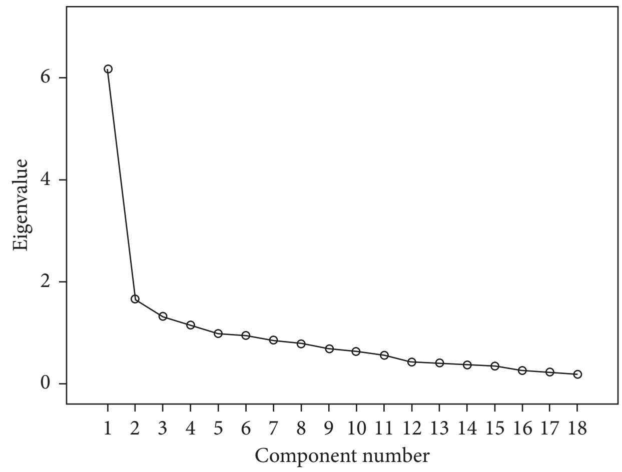

Figure 3: Scree plot.

Table 5: Factor analysis: factor loading and the percentage variance explained.

Name of the factor	Factor loading	% variance explained
Factor 1: decision-related		
11. Communication	0.725	17.911%
12. Coordination	0.698	—
8. Conflict	0.673	—
5. Real-time monitoring and proactive decision making	0.595	—
7. Complexity	0.520	—
6. Capacity	0.467	—
Factor 2: project environment-related		
14. Dynamic nature	0.748	15.613%
13. Volatile economic environment	0.702	—
10. Context	0.646	—
15. Duration and resources (cascade effect)	0.614	—
9. Commitment	0.538	—
Factor 3: project management-related		
17. Project manager assignment	0.861	14.107%
16. Competencies of project manager	0.828	—
18. Project management processes (information sharing)	0.635	—
1. Division and assignment of resources/resource allocation	0.431	—
Factor 4: organization-related		
3. Management support	0.767	9.543%
2. Organizational culture	0.748	—

Table 6: Pearson correlation coefficient matrix for the variables in factor 1.

Variables	11	12	8	5	7	6
11	1	—	—	—	—	—
12	0.575	1	—	—	—	—
8	0.390	0.370	1	—	—	—
5	0.512	0.549	0.277	1	—	—
7	0.417	0.284	0.406	0.376	1	—
6	0.475	0.353	0.288	0.307	0.465	1

empower the decision-making capabilities. Hence, factor 1 is labeled as decision-related. Factor 2 explains the total variance of 15.613% and comprises five variables (Table 5). In Table 7, factor 2 variables have the Pearson correlation coefficient values between 0.370 and 0.641. The variables' dynamic nature, volatile economic environment, context, duration and resources, and commitment to this factor concentrate on the project environment-related issues. Therefore, factor 2 is considered as project environment-related. Factor 3 explains the total variance of 14.107% and includes four variables (Table 5). In Table 8, factor 3 variables have the Pearson correlation coefficient values between 0.225 and 0.716. The variables project manager assignment, competencies of project manager, project management processes, and division and assignment of resources under this factor focus on the project management aspects. Thus, factor 3 is termed as project management-related. Factor 4

Table 7: Pearson correlation coefficient matrix for the variables in factor 2.

Variables	13	14	10	15	9
13	1	—	—	—	—
14	0.426	1	—	—	—
10	0.446	0.441	1	—	—
15	0.436	0.513	0.426	1	—
9	0.441	0.370	0.641	0.427	1

Table 8: Pearson correlation coefficient matrix for the variables in factor 3.

Variables	17	16	18	1
17	1	—	—	—
16	0.716	1	—	—
18	0.580	0.517	1	—
1	0.261	0.259	0.225	1

explains the total variance of 9.543% and contains two variables (Table 5). The value of Pearson correlation coefficient for the variables in factor 4 is 0.327. The variables management support and organizational culture focus on the organizational aspects. Hence, factor 4 is labeled as organization-related. Similar research studies have been found earlier; however, those [26, 27] are merely on the relative importance index.

Cronbach's alpha test was conducted for all variables as well as variables in each factor. The value of Cronbach's alpha lies in the range of 0 to 1; higher value indicates greater internal consistency and vice versa. C_α value higher than 0.7 is considered to be acceptable: the variables in factor 1 (0.793), the variables in factor 2 (0.806), the variables in factor 3 (0.757), and all variables (0.880). C_α value is unacceptable for the variables in factor 4 (0.486); the reason might be the existence of only two variables.

4.3. Resource-Unconstrained Multiproject Scheduling Problems and Practices. Resource-unconstrained situation exists in staff cadre only. The resources are set to be unconstrained only when the time is constrained. Resource-unconstrained projects face many difficulties: (a) optimal use of resources; (b) control of resource wastes; (c) lavish use of resources leads to cost overruns and profit loss; (d) underutilization of resources; and (e) lack of coordination, communication, and commitment. Resource-unconstrained projects can be efficiently handled through: (a) identifying the adequate work front; (b) multiple authorities for decision making; (c) reconciling the resource allocations at regular intervals (proactive resource planning); (d) optimization of resources by implementing real-time productivity tracking; (e) awareness of selection and deployment of resources to suit the budget, specification, and timeframe; (f) pull planning and restriction analysis before the start of task; (g) effective communication strategies with project heads on a regular basis for resource allocation; (h) creating common resource pool and charge the projects on rental basis; (i) key personnel should be trained to use management tools at all levels of project; and (j) migrate the minset towards resource-constrained schedules.

4.4. Resource-Constrained Multiproject Scheduling Problems and Practices. Resource-constrained projects face issues in (a) prioritization of resources based on experience and critical path identification; (b) lack of coordination, communication, and collaboration; (c) unskilled labor; (d) outdated machinery; (f) unqualified supervision; (g) quality issues; (h) reworks; and (i) awareness of using new technologies. Resource-constrained projects can be handled efficiently through: (a) increased supervision, (b) proper training, (c) top-up via subcontracting, (d) overtime works, (e) closely monitoring the productivity, (f) implementing lessons learnt from past experiences, (g) better coordination and extensive use of schedules, (h) use of competent project management tools, (i) proactive pull planning and monitoring on a regular basis, (j) introduction of buffers, (k) accountability on achieving the cycle time, (l) centralized database with active communication channel, (m) culture of the organization's need to train for cooperation, (n) alternative planning options in terms of whether to buy or hire the number of required resources, (o) automating the repetitive activities to eliminate the variances and improve the reliability, (p) incentives to retain the skilled workmen, and (q) crashing activities for resource smoothing.

4.5. The Various Aspects of the Multiproject Environment (MPE). The descriptive information of the various multiproject environment aspects was tabulated (Table 9). Chi-square goodness-of-fit test was performed to check whether the following multiproject environment aspects are equally preferred among the practitioners (Table 10). The multiproject approach is preferred over the single-project approach. The test confirmed that statistically, a significant difference exists. The reason is that in the multiproject approach, each project is considered independent of other projects to minimize the average project delay. Activities can be executed with the different combinations of construction methods, materials, and crew sizes. It is highly significant because the baseline planned resources may not be available during the actual construction. Therefore, variability in the duration of execution has to be minimized. The different activity execution modes can take various performances of time, cost, and quality. However, some of the activities have to be complete based on their baseline specifications because of contractual conditions. Therefore, single and multiple execution modes are required to complete all tasks in the project. There is a significant difference exists between single mode, multimode, and preferring both execution modes.

Centralized decision-making model is preferred for long duration projects whereas decentralized model is preferred for short duration projects. Centralized model is effective in controlling the progress throughout the project management process. Project value above INR 500 million is considered under the centralized model. To adopt the efficient centralized model, the information should flow from bottom to top and then top to bottom with active

Table 9: Descriptive information on the various aspects of the multiproject environment.

Aspects of the multiproject environment		Counts ($n = 90$)
1. Network modeling approach	(a) Single-project approach	16
	(b) Multiproject approach	74
2. Activity execution modes	(a) Single mode	16
	(b) Multimode	71
	(c) Both	3
3. Decision-making models	(a) Centralized	40
	(b) Decentralized	28
	(c) Both	22
4. Solution methods	(a) Exact	14
	(b) Heuristics	54
	(c) Metaheuristics	18
	(d) Not aware	4

Table 10: Chi-square goodness of fit for the various aspects of the multiproject environment.

Result	Summary	
	Aspects of the multiproject environment	Chi-square
Significant difference exists	Single-project and multiproject approach	χ^2 (1, N = 90) 37.38, $p < 0.05$
	Single, multiple, and both activity execution modes	χ^2 (2, N = 90) 86.87, $p < 0.05$
	Exact, heuristics, metaheuristics, and not aware	χ^2 (3, N = 90) 63.42, $p < 0.05$
Significant difference does not exists	Centralized, decentralized, and combined decision-making model	χ^2 (2, N = 90) = 5.60, $p > 0.05$

communication channels. The centralized model is considered when projects of similar type are clustered together, and monitoring of progress is performed under the same unit. The decentralized model enables decisions required at the site operational level. The operational level decisions can be decentralized, and tactical level decisions can be centralized. Table 9 shows the preference order of decision-making models. However, statistically, differences do not exist. Therefore, the mixed decision making is needed to execute the projects enabling proper communication, coordination, and collaborative channels. Exact approaches give the best solution but take much computational time and also complex; heuristics provide approximate solutions but may not be accurate; and metaheuristic can give optimal/near optimal solutions. The preference of solution methods is shown in Table 9. There exists a significant difference among the means (Table 10). It indicates that currently rule-based heuristics are widely used. However, respondents were suggested that robust approach is required to assist the real-time decision-making capabilities.

Resource sharing, dedicating, and substituting are useful for efficient use of limited available resources. It helps smooth functioning of multiple projects. However, it requires unmatched coordination among the multiple projects. The systematic solutions for these concepts are under-developed. Substituting resources are useful when finding same specification resources without affecting the project quality. Reactive and proactive planning is essential for these concepts. Many project management tools were used for its processes. However, the real-time monitoring and decision-making capability are always questionable, because of various multiproject environment aspects.

In the resource-constrained situation, the critical chain can be used. While preparing the baseline schedule of the project, periodic brainstorming should be done considering the construction techniques, risks, equipment, and manpower involved. Resource-constrained multiproject scheduling is more realistic and helps in achieving project targets with minimum deviation from milestones than resource-unconstrained schedules. The supply chain should interact for resource mobilization and identification of the source and place the orders well in advance as per microplanning. The synergy among stakeholders required to implement the project at corporate level planning, contract, site execution, monitoring, and control. Influence of BIM and other IT tools can combine to interact all stakeholders effectively, but BIM requires blend-in time to fit the organization. Due to the complexity of multiproject environment, experienced manpower should be deployed. The staff and labor should also be trained appropriately. Multiproject scheduling under resource-constrained situation requires more significant experience and can be done with the help of technologies.

5. Conclusions

There is a pressing need to find solution strategies for the resource-constrained multiproject scheduling problems since many companies work in the multiproject context with limited resources. The identified top challenging issues are (a) real-time monitoring and proactive decision making, (b) division and assignment of resources/resource allocation, (c) project management processes (information sharing), (d) coordination, (e) communication, and (f) competencies of project manager. Factor analysis identifies the following factors to improve the multiproject environment capabilities: (a) decision-related, (b) project environment-related, (c) project management-related, and (d) organization-related.

Resource-unconstrained situation does not address the issue of underutilization and wastage of resources leading to lower profit realization. The findings suggest that the following should be considered in resource management: identifying the work front, adopting pull planning approach, creating a common resource pool with resources allotted on a rental basis, a training programme to the staff, and finally migrating the mindset to the resource-constrained environment.

The resource-constrained situation needs to accommodate the following: prioritization of resources, coordination, communication, collaboration, unskilled labor, outdated machinery, unqualified supervision, quality issues, rework, and use of new technologies. The findings suggested top-up via subcontracting, proactive pull planning, introducing buffers (critical chain), proper training, working overtime, training the culture of the organization towards better communication, coordination, and collaboration and automating repetitive activities to improve the reliability of achieving baseline project performances.

Various multiproject strategies are suggested for effective management: explicit use of the multiproject approach in scheduling, the combined use of single and multimode activity execution modes, integrated nature of centralized and decentralized decision-making models, and robust solution approaches required to assist the real-time decision-making capabilities. Sharing, dedicating, and substituting resources which are highly relevant to the multiproject environment requires unmatched coordination. It was suggested that intelligent decision-making tools could enable efficient use of limited resources in the multiproject environment. The problems identified in the present study and the current practices that have been revealed through the survey are expected to contribute better project management in the construction industry. The limitation of this study is the smaller sample size. The future research directions could be (a) developing efficient decision-making algorithm for resource-constrained multiproject scheduling and (b) adopting a lean-based approach for the effective management of constrained resources.

Data Availability

The questionnaire survey data were collected confidentially and so cannot be made available.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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