

Scheduling of Repetitive Projects with Multiple Objectives by Multiple Crew Model

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In repetitive projects, different activities get repeated from one location to another. In many such cases, there will be different crew alternatives on hand for completing an activity and choosing the finest option from available peculiar resource choices for each activity is a crucial responsibility for the managers of a project. Obtaining a best schedule, examining various project objectives (total expenditure, total time span etc.) is of greatest significance in any project sector. The present paper proposes a mathematical model considering a multiple crew model, which can satisfy the various objectives related to the constraints like crew availability in various units, precedence relationship between various activities and units and penalty cost corresponding to the delaying day of each activity in every area of site etc. The present model is optimally solved using a mathematical solver and justified its authenticity by applying complete enumeration technique (in the case of small size problems). For abundant type problems, a heuristic technique is absolutely necessary to get a best schedule, as the mathematical solver, as expected, fails because of the computational complexity involved. Therefore, this paper also proposes a new heuristic methodology. The efficiency of the proposed method was compared using the optimal solutions obtained from the developed mathematical model, and it can be seen that the heuristic methodology provided a near-optimal solution. In this paper, the multiple crew model was also compared with the single crew model, and it can be seen that the present model yielded comparatively better results than the previous one.

Keywords: Complete enumeration technique, Heuristic method, Mathematical model, Project management, Project scheduling

Notations

i	Activity
j	Project site
i'	Successor activity i
j'	Successor project site j
M	Total activities
Q	Total project sites
n	Crew options in an activity
ST_{ij}	Start time of activity i in site j
ST'_{ij}	Start time of successor activity i' in project site j
$ST'_{ij'}$	Start time of activity i in successor project site j'
FT_{ij}	Finish time of activity i in project site j
C_o	Original cost for the project
p_i	Cost for penalty in unit duration with respect to activity i
LT_{ij}	Duration with respect to lagging of an activity i in site j
DT_{ij}	Due time of activity i in unit j
IC	Indirect expenses per unit duration
TD	Total project duration
C	Total project cost
d_{ki}	Durations with respect to unit amount of work of k^{th} crew in activity i
c_{ki}	Direct cost with respect to unit amount of work of k^{th} crew in activity i
qw_{ij}	Quantity of work of activity i in site j
wt_c	Assigned weight with respect to duration

wt_c Assigned weight with respect to cost

L A large value

T_{\min} Minimum time

C_{\min} Minimum cost

$x_{kij} \begin{cases} 1 & \text{if } k \text{ th crew of } i \text{ th activity is assigned to } j \text{ th unit} \\ 0 & \text{otherwise} \end{cases}$

$Y_{kijj'} \begin{cases} 1 & \text{if } k \text{ th crew of } i \text{ th activity is assigned to } j' \text{ th site} \\ 0 & \text{otherwise} \end{cases}$

Introduction

A project encompasses a set of tasks essential for achieving a well-defined objective, typically characterized by three primary aims: meeting requirements, managing expenses, and adhering to deadlines. These objectives often conflict with each other, requiring project decision makers to strive for a balance between them. Additionally, the complexities inherent in a project's lifecycle present significant challenges. This often results in prolonged completion times for large-scale projects. Project management involves the systematic application of theory, experience, tools, and techniques across various activities to fulfill the diverse needs of a project. Linear or repetitive projects include recurring tasks, which are commonly encountered in endeavors such as constructing building complexes, housing projects,

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pipeline networks, highways, airport facilities, railway infrastructure, bridges, tunnels, sewer systems, and mass transit networks.

We can see a lot of repetitive project scheduling methods in the literature and most of these are based on the concept that a repetitive project consists of a number of uniform production units. A unit consists of different activities which is represented as a unit network and is repeated from one unit to other. Usually a particular crew/resource is appointed/allotted to each operation in the unit setup. The appointed team completes the work related to that activity serially and successively in different units. Each work is completed in the sequential order of different units. But in real situation, different units in many repetitive projects may not be uniform in nature.¹ For example, the capacity and structure of each storage chamber might potentially be dissimilar in a plant for several storage units. Also, the number of nozzles and pipe sections will not commonly be the identical in the different units of a pipeline project and therefore the quantity of work as well as the project duration and expenditure will differ. There are various methods available for the sustained usage of crews from a process in one spot to the repeated process in the next spot. These techniques were in development for many years and have been reported by various titles. For projects with different units such as houses, apartments, stores, floors, pipe sections, shells of vessels, offices etc., different techniques like Line of Balance (LOB)^{2,3}, Construction Planning Technique (CPT)⁴, or the Repetitive Scheduling Method (RSM)⁵ were in existence. Heuristics techniques have proven to be very useful when solving complex optimization problems in repetitive project scheduling.^{6,7}

Lot of researchers have developed different methods by applying exact and heuristic procedures for finding out the schedule for repetitive project and most of these models deal with single objective problems.^{8,9} In real scenario, a decision maker in a project may want to react to conflicting objectives. Therefore the application of multi-objective optimization is most important in repetitive project works.¹⁰ But there are only exceptionally limited number of works in the literature that handles optimization of multiple objectives.^{11,12} The lagging of various activities is a major issue in any project. For eliminating this challenge, most of the project organisations are forced to pay a penalty cost

corresponding to the delay in different activities of different project sites. Therefore, a methodology which also consider a monetary consequence of task delay is very important; as there exists only very less number of articles in the literature that discusses this kind of problems, in repetitive project scheduling.^{13,14}

Developing schedules for repetitive projects presents a significant challenge for project decision-makers. These projects require a steady movement of teams between locations, with identical tasks being performed sequentially while maintaining the precedence relationships between various activities.^{15,16} The primary objective is to devise a technique that can generate successful schedules, minimizing both cost and duration, while addressing constraints such as activity precedence, resource continuity, availability, and delivery deadlines across different project sites. This necessitates careful coordination and optimization to ensure efficient utilization of resources and timely completion of tasks at each site.¹³

Another important factor noted from the literature survey is that most of the researchers do not consider the situation wherein multiple crews work simultaneously in various locations on the same activity. But in real situation, how to assign the available number of crews to a construction activity occurring in all repetitive units of the project is very significant. It can be seen that some project companies follow a method in which they choose a specific resource option for each task and it shift along various units to complete the task.¹³ But there are also others, who select different crews/resources and move/use them simultaneously to different work sites for completing the task. The present study considers the second scenario, which has not been discussed in any literature regarding repetitive project scheduling.

The principal objective of this paper is to develop suitable techniques which can find an optimal schedule for a multiple crew repetitive project scheduling problem, satisfying different objectives like minimize project duration, minimize total outlay for the project and minimize the joint influence of timeline and budget.

Model Description

The project work described involves different activities across various sites, such as housing projects and pipeline networks. These activities

follow a specific precedence order and are repeated at different locations.^{17,18} Various resource choices are assigned to each task, with particular timeframes and expenses per work unit tied to each resource or team. This model encompasses multiple crews working simultaneously, in sequence, or a combination of both, hence the term "multiple crew model." The study focuses on identifying an optimal schedule that minimizes project duration, project cost, and both factors together, while adhering to constraints such as resource work continuity, resource availability, precedence relationships between activities, and time limits for each activity's completion at every site.

Mathematical Model

Minimize project duration (Objective 1)

$$T_{\min} = \text{Min} \{ \text{Max} \sum_{i=1}^M \sum_{j=1}^Q \sum_{k=1}^n x_{kij} \times (ST_{ij} + (d_{ki} \times qw_{ij})) \} \quad \dots (1)$$

Minimize project cost (Objective 2)

$$C_{\min} = \text{Min} \{ \sum_{i=1}^M \sum_{j=1}^Q \sum_{k=1}^n x_{kij} \times (c_{ki} \times qw_{ij}) + (LT_{ij} \times p_i) \} + (IC \times \text{Max} \sum_{i=1}^M \sum_{j=1}^Q \sum_{k=1}^n x_{kij} \times (ST_{ij} + (d_{ki} \times qw_{ij}))) + C_o \} \quad \dots (2)$$

Minimize combined effect of both project cost and project duration (Objective 3)

$$\sqrt{(w_t \left(\frac{T - T_{\min}}{T_{\min}} \right)^2) + (w_c \left(\frac{C - C_{\min}}{C_{\min}} \right)^2)} \quad \dots (3)$$

Subject to

$$LT_{ij} = \text{Max} (0, FT_{ij} - DT_{ij}) \quad \dots (4)$$

$$\sum_{k=1}^N x_{kij} = 1 \quad i=1,2,\dots,M \quad j=1,2,\dots,Q \quad \dots (5)$$

$$\sum_{j=1}^Q \sum_{k=1}^N x_{kij} = Q \quad i=1,2,\dots,M. \quad \dots (6)$$

$$\sum_{k=1}^N x_{kij} \times (ST_{ij} + (d_{ki} \times qw_{ij})) \leq ST_{i'j} \quad i=1,2,\dots,M; \quad j=1,2,\dots,Q. \quad \dots (7)$$

$$FT_{ij} \times \sum_{k=1}^N x_{kij} \leq ST_{i'j} \quad i=1,2,\dots,M; \quad j=1,2,\dots,Q \quad \dots (8)$$

$$x_{kij} \times (ST_{ij} + (d_{ki} \times qw_{ij})) - L \times (1 - Y_{kijj'}) \leq ST_{i'j}$$

$$i=1,2,\dots,M; \quad j=1,2,\dots,Q; \quad k=1,2,\dots,N \quad \dots (9)$$

$$FT_{ij} \times x_{kij} - L \times (1 - Y_{kijj'}) \leq ST_{i'j}$$

$$i=1,2,\dots,M; \quad j=1,2,\dots,Q; \quad k=1,2,\dots,N \quad \dots (10)$$

$$\sum_{k=1}^N x_{kij} \times (ST_{ij} + (d_{ki} \times qw_{ij})) = FT_{ij}$$

$$i=1,2,\dots,M; \quad j=1,2,\dots,Q \quad \dots (11)$$

$$x_{kij} \times (ST_{ij} + FT_{ij}) \leq L \quad i=1,2,\dots,M; \quad j=1,2,\dots,Q; \quad k=1,2,\dots,N \quad \dots (12)$$

With

$$x_{kij}, Y_{kijj'} \in \{0,1\}$$

$$d_{ki}, c_{ki}, ST_{ij}, ST_{i'j}, ST_{ij'}, FT_{ij}, LT_{ij} \geq 0$$

The objectives to reduce project duration and project cost are described in Eqs 1 & 2, while Eq. 3 focuses on lessening the joint impact of both duration and cost. The goal of Eq. 1 is to identify the optimal project duration by minimizing the completion time of all activities across all units. This equation calculates the duration of a specific activity within a unit by multiplying the Time needed for completing a unit of work of the kth crew for the ith activity with the workload of the ith task in the jth site. The effort to minimize total project cost is represented by Eq. 2, which includes total direct expenses, total overhead expenses, total penalty fees and original cost. Total direct cost is calculated by multiplying direct expense per unit of work of each activity's specified crew with the workload for that task in each location. Cumulative penalty fees is determined by multiplying the lateness time of task i in location j with the cost of penalties associated with activity i. Total indirect cost is computed by multiplying the indirect cost per unit duration with the overall project duration. In Eq. 3, the combined effect value is calculated by applying specified weights set by the project's decision makers, who evaluate the proportional significance of project time span and overall project expenses. The weight coefficients are chosen independently within the range of [0.0, 1.0], ensuring that their sum equals 1.0. T and C represent the compromise solutions for complete project timeline and project expenses as determined by Eq. 3. Optimal values for project timeline and total expenses, corresponding to the single objective optimization of duration and cost, are derived independently by working through equations 1 and 2 respectively, according to their specific objectives. The aim of Eq. 3 is to find the best trade-off result that minimizes the relative deviation from the single objective solutions (T_{min}, C_{min}).¹⁹

In Eq. 4, the lateness time of each activity in every site is represented as either zero or difference between the finish time (FT_{ij}) and deadline (DT_{ij}) of i^{th} activity in j^{th} site. The constraint for the crew option assigned to a particular activity in a particular unit is represented by Eq. 5. If we select a crew k for activity i in site j , then its x_{kij} (k^{th} crew of i^{th} activity in j^{th} site) should be equal to one. This equation would not allow the selection of any other crew for the particular activity in that site. The selected crew of each activity is available on that particular site till its completion without break. The requirement that any one of the crews of each activity must be assigned to every project site is ensured by Eq. 6. So if there are ' Q ' number of sites, then ' Q ' number of crew must be selected. This equation permits assigning of a particular crew of a particular activity to one or more sites.

The constraint function in Eq. 7 requires that the sum of the beginning time of the i^{th} task at the j^{th} site (ST_{ij}) and the duration of the i^{th} activity at the j^{th} site (calculated as the product of the duration for each unit of work of the k^{th} crew (d_{ki}) and the workload for the i^{th} task at j^{th} site (qw_{ij})) should be less than or equal to the beginning time of the successor task i' at the same site j ($ST_{i'j}$). Multiplied by an integer parameter, x_{kij} , which depends on whether the k^{th} crew is involved in the i^{th} activity at j^{th} site, the equation specifies the logical sequence of tasks. Additionally, Eq. 8 emphasizes that the end time of the i^{th} task at the j^{th} site (FT_{ij}) must precede the beginning time of the successor task i' at the same site j ($ST_{i'j}$), ensuring that no successor activity begins before the completion of the current task.

The logical relationships among different units in a particular activity are represented in Eq. 9 and Eq. 10. In multiple crew model, a particular crew may be selected to one site, two site or Q number of sites depending on the objective functions. If there are Q number of sites and each site has an independent crew, then all the crew must be working simultaneously on different sites. But if a particular crew is selected for more than one site, the crew, after completing the work on the first site, moves to the next/other site to complete the work. In this situation, starting time of successor site should be not less than the finishing time of current site. So here two integer parameters should be considered x_{kij} (k^{th} group of i^{th} task in j^{th} site) and $Y_{kijj'}$ (k^{th} workforce of i^{th} task is

allocated to j^{th} site which is the successor of j^{th} site). $Y_{kijj'}$ is assigned to 1 if the same crew repeats from site j to site j' in activity i , otherwise it is assigned as 0. So, from that equation we can see that if the same crew moves from j to j' site, then start time of j' site should be greater than or equal to a value which is the sum of start time and duration of j^{th} site. If a separate crew is assigned to a site j' , then the large value (L) assigned to that function is helpful in keeping the start time of j' site which is not influenced by any other site j . The same process will be applied to the Eq. 10 where the relationship between the beginning time of j' site and end time of j^{th} site are fixed.

The start-finish relationship for each activity across all sites is characterized by Eq. 11. This equation calculates the completion time of each activity by adding its start time to its duration in a given site. Meanwhile, Eq. 12 establishes the parameter L , ensuring it remains equal to or greater than the sum of the beginning and end times of any task within a specific site.

Solution Methodology

This paper follows the same approach as the journal regarding the single crew model,¹³ but it accounts for numerous groups operating concurrently across separate divisions. Consequently, the model has been adjusted to accommodate this change in methodology. The paper proposes two different approaches to determine the result for the problem under study. The initial approach involves constructing a mathematical programming model to derive optimal solutions for the three specified objectives. This model is subsequently solved utilizing the IBM ILOG Cplex 12.5 optimizer to obtain optimal solutions to achieve the goals outlined in this study. Additionally, to validate the model's accuracy, a complete enumeration technique is employed, particularly suitable for smaller-sized problems. In this technique, Excel software is utilized to generate a comprehensive schedule corresponding to the problem, enabling the selection of the optimal solution based on the different objectives under consideration. As we all know, the major downside of this methodology is the computational complexity and the solver may prematurely terminate in the case of large problem instances. A heuristic can be helpful in such conditions as it can obtain good approximate answers in precise time with nominal computational effort²⁰ [Back Thomas (1996)]. The benefit of

applying such a technique in this case is that the system can be simulated for any number of time units as required; moreover, the results can be attained really fast, compared to a solver.

IIPDMGA-MCRPS based Methodology

Choosing an ideal crew utilization option from the accessible set of possible choices in a large size problem is a tough job for a solver based solution technique. Here the computational time increase exponentially, as size of problem increases and after a certain threshold, the solver stops, citing constraints on execution. In most of these problems, the possible solution options generate a large search space where each result produces a suitable alternative for completing the project. For instance, a project that comprises 20 distinct tasks, each offering 5 different crew choices and 10 sites in which work is going on simultaneously, creates a search space of $(5^{20})^{10}$ possible solutions. Thus, a new methodology, referred to as IIPDMGA-MCRPS (Initially Improved Population and Dynamic Mutation in GA for Multiple Crew Repetitive Project Scheduling), is being introduced to solve computationally complicated large problem instances where exact solution techniques are not feasible. To validate the proposed solution methodology, heuristic solutions generated for small-sized problems are compared with those obtained using a mathematical solver. In this research, the time required for each unit of work in the tasks have been used as decision variables, representing the genes of the chromosome within the IIPDMGA-MCRPS framework. The initial population is created randomly, and the structure of the chromosome is depicted in Fig. 1, where d_{11} , d_{12} , d_{13} , and so forth indicate the time needed for each unit of work for task 1 across different sites such as site 1, site 2, site 3, and so on. Each chromosome provides a feasible schedule that adheres to the requirements of the problem at hand.

Given a project composed of m activities and n units, each chromosome within the IIPDMGA-MCRPS framework encompasses $m \times n$ decision variables. These decision variables determine the crew alternatives for each activity at every site. The genes within each chromosome guide the selection process, which identifies the time needed for each unit of work of the k^{th} crew for the i^{th} activity as well as expense for each unit of work of the k^{th} crew for the i^{th} activity at each site. This approach ensures that the

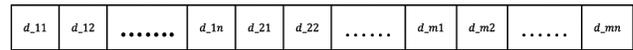


Fig. 1 — Chromosome representation of IIPDMGA-MCRPS

most suitable crew alternatives are chosen for each activity in every site based on the genetic makeup of each chromosome.

In the IIPDMGA-MCRPS framework, a scheduling algorithm is implemented to evaluate how suitable each chromosome is within the population. When dealing with a combined objective function, Eq. 3 is used to calculate the fitness function. After assessing suitability, every chromosome in the starting population generates a new chromosome randomly within its neighbourhood. The fitness value of the newly created neighbouring solution is then assessed and compared to the existing one. The fitter solution is selected for retention, ensuring an optimization of the population based on the best available fitness values.

In the IIPDMGA-MCRPS framework, forming a new population for the upcoming generation requires applying selection, crossover, and mutation methods.^{21,22} The fitness of each chromosome is defined based on the project timeline, project budget, or a combined measure of both factors, depending on whether the objective is to minimize duration, cost, or a combination of both. The likelihood of choosing a particular chromosome is directly related to its fitness, making chromosomes with better fitness more likely to be selected for reproduction and the creation of new generations.

Parameter setting is a major aspect that influences the performance of proposed IIPDMGA-MCRPS. A pilot study conducted in a small size problem using IIPDMGA-MCRPS with different combination of parameters and obtained various solutions corresponding to those parameters. From the pilot study, it is found out that a fluctuating mutation rate proves to be more effective than a fixed rate. The above values were arrived after conducting extensive testing of different values suggested in the literature. Therefore, a dynamic mutation rate is applied in IIPDMGA-MCRPS, where mutation rate varies according to the increasing number of generations.

The heuristic is implemented using MATLAB R 2018a and executed on a system with an Intel(R) Core(TM) i3-7100U CPU operating at 2.40 GHz, equipped with 4 GB RAM, and running Windows 10 Home Single Language.

Table 1 — Findings for the first objective of the problem

Methodology	Seed	Duration (days)	Cost (Rs)	Schedule
IIPDMGA-MCRPS	Seed 1	103	1305460	A1 B1 C3 D4 E2; A1 B2 C1 D1 E1; A1 B1 C3 D4 E2; A1 B1 C3 D1 E1
	Seed 2	103	1302612	A1 B1 C3 D4 E1; A1 B2 C1 D1 E2; A1 B1 C3 D1 E2; A1 B1 C3 D1 E1
	Seed 3	103	1302612	A1 B1 C3 D4 E2; A1 B2 C1 D1 E2; A1 B1 C3 D1 E2; A1 B1 C3 D1 E1
	Seed 4	103	1273378	A1 B1 C1 D4 E2; A1 B2 C1 D1 E2; A1 B1 C3 D4 E2; A1 B1 C3 D1 E1
	Seed 5	103	1273378	A1 B1 C1 D4 E2; A1 B2 C1 D1 E2; A1 B1 C3 D4 E2; A1 B1 C3 D1 E1
CPLEX Solver	Optimum	103	1304575	A1 B1 C3 D2 E1; A1 B2 C1 D1 E1; A1 B1 C3 D4 E2; A1 B2 C3 D1 E1

Table 2 — Findings for the second objective of the problem

Methodology	Seed	Cost (Rs)	Duration (days)	Schedule
IIPDMGA-MCRPS	Seed 1	1070544	134	A1 B3 C1 D1 E2; A1 B3 C1 D1 E1; A1 B3 C1 D1 E1; A1 B3 C1 D1 E1
	Seed 2	1070544	134	A1 B3 C1 D1 E2; A1 B3 C1 D1 E1; A1 B3 C1 D1 E1; A1 B3 C1 D1 E1
	Seed 3	1070544	134	A1 B3 C1 D1 E2; A1 B3 C1 D1 E1; A1 B3 C1 D1 E1; A1 B3 C1 D1 E1
	Seed 4	1070558	134	A1 B3 C1 D1 E2; A1 B3 C1 D1 E1; A1 B3 C1 D1 E1; A1 B2 C1 D1 E1
	Seed 5	1070558	134	A1 B3 C1 D1 E2; A1 B3 C1 D1 E1; A1 B3 C1 D1 E1; A1 B2 C1 D1 E1
CPLEX Solver	Optimum	1070544	134	A1 B3 C1 D1 E2; A1 B3 C1 D1 E1; A1 B3 C1 D1 E1; A1 B3 C1 D1 E1

Table 3 — Findings for the third objective of the problem

Methodology	Seed	Min Combined effect	Duration (days)	Cost (Rs)	Schedule
IIPDMGA-MCRPS	Seed 1	0.04558	106	1132309	A1 B3 C1 D1 E1; A1 B3 C2 D1 E1; A1 B2 C1 D2 E2; A1 B1 C2 D1 E1
	Seed 2	0.0487	107	1131700	A1 B3 C1 D1 E1; A1 B3 C2 D1 E1; A1 B2 C1 D1 E2; A1 B1 C2 D2 E1
	Seed 3	0.04558	106	1132309	A1 B3 C1 D1 E1; A1 B3 C2 D1 E1; A1 B2 C1 D2 E2; A1 B1 C2 D1 E1
	Seed 4	0.04558	106	1132309	A1 B3 C1 D1 E1; A1 B3 C2 D1 E1; A1 B2 C1 D2 E2; A1 B1 C2 D1 E1
	Seed 5	0.0487	107	1131700	A1 B3 C1 D1 E1; A1 B3 C2 D1 E1; A1 B2 C1 D1 E2; A1 B1 C2 D2 E1
CPLEX Solver	Optimum	0.04558	106	1132309	A1-B3-C1-D1-E1; A1-B3-C2-D1-E1; A1-B2-C1-D2-E2; A1-B1-C2-D1-E1

Table 4 — Solution corresponding to multi objective optimization in problem using IIPDMGA-MCRPS

Weights	$w_t = 1, w_c = 0$	$w_t = 0.8, w_c = 0.2$	$w_t = 0.7, w_c = 0.3$	$w_t = 0.6, w_c = 0.4$	$w_t = 0.5, w_c = 0.5$	$w_t = 0.4, w_c = 0.6$	$w_t = 0.3, w_c = 0.7$	$w_t = 0.2, w_c = 0.8$	$w_t = 0, w_c = 1$
Duration (Days)	103	106	106	106	106	106	106	109	134
Cost (Rs)	1304575	1132309	1132309	1132309	1132309	1132309	1132309	1122800	1070544

Test Problem with Results and Discussion Problem

Here we consider a 5 activity, 4 unit problem as discussed in Mathew *et al.*¹³ For testing this problem using multiple crew model, five distinct sequences of pseudo-random numbers (seed 1, seed 2 etc) are applied²³ and the results obtained using IIPDMGA-MCRPS for three target functions are shown in Tables 1 to 3. Total 6561 viable solutions can be achieved in this problem. Here, we observe that the heuristic techniques provide solutions across different random number sequences, and these solutions are

consistently close to one another. Additionally, they yield optimal or near-optimal solutions across three different objective functions, as obtained with the help of the CPLEX solver.

Multi-Objective Optimization

For simultaneously optimizing both the objectives, we know that there should not exist a single solution. Hence different weightages are applied to the objectives and results are shown in Table 4. In multiple crew model, some combinations give good results which satisfies both objectives in a good way.

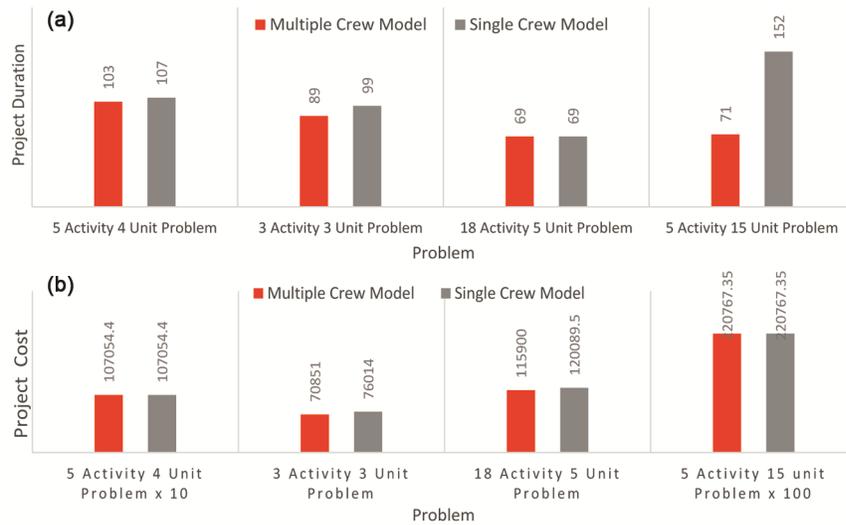


Fig. 2 — Comparison of single crew model and multiple crew model in different problems for: (a) the objective 1, and (b) objective 2

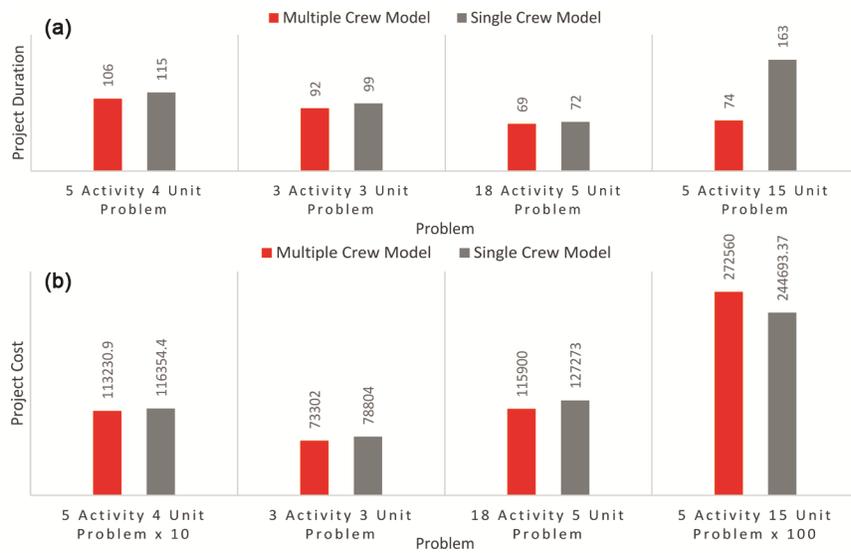


Fig. 3 — Comparison of single crew model and multiple crew model corresponding to objective 3 (equal weightage to duration and cost) in different problems for (a) the duration, and (b) cost

Hence, the same results are repeating in few cases wherein the different combination of weights is close to each other.

Comparison with Single Crew Model

In this session, the performance of the multiple crew model is compared with the single crew model²² with respect to different objectives, as shown in the Figs 2&3. There are four different problems, each with varying problem sizes. From the figures, one can see that multiple crew model gives comparatively good results with respect to single crew model in almost all the problems. But in some cases, wherein objective 2 (cost) was considered mixed results were

obtained as the single crew model also give same or nearer results in comparison to multiple crew model. This is because of the cost settings and fixed costs assumed in this study, as using multiple crews may increase cost depending on the projects chosen. In these cases, wherein cost is a major factor, the decision maker may choose the crew model which will help him in managing the project.

Conclusions

This paper addresses scheduling challenges in repetitive projects, aiming to reduce both project timeline and costs through single-objective and multi-objective optimization within a multiple crew model.

Precedence relationships among project sites, activity dependencies, resource availability, and due dates across project units are analysed. A mathematical model is formulated and evaluated using the CPLEX solver, with its effectiveness demonstrated. Additionally, a novel heuristic method, IIPDMGA-MCRPS, is utilized to efficiently handle large-scale problems, providing solutions that are nearly optimal with negligible mean percentage difference across all goals. Both the mathematical model and heuristic are utilized to provide insights for decision-makers in generating effective schedules. The uncertainty inherent in repetitive project executions is acknowledged, and future extensions involving probabilistic data are considered. With advancements in computational power, newer algorithms capable of solving large multiple crew repetitive project scheduling problems with minimal computational effort could also be developed.

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