Time Optimization for Resource-Constrained Project Scheduling Using Meta-heuristic Approach

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Abstract— **This paper presents a method to minimize the duration of the project using a structured method by defining and evaluating multiple constraints such as precedence constraints, resource constraints and deadline constraints. Resource-Constrained Project Scheduling Problem (RCPSP) considers resources of limited availability and activities of known durations and resources requests, linked by precedence relations. The problem consists of finding a schedule of minimal duration by assigning a start time to each activity such that the precedence relations and the resource availabilities and deadline constraints are represented. Comparing to classical optimization techniques, meta-heuristic optimization techniques require less time to find the optimal solution for complex problems like RCPSP. Out of several meta-heuristic techniques, Genetic Algorithm is chosen for optimization. In this research, two problems from literature and two real life problems are chosen for time optimization using Genetic Algorithm (GA). All the GA parameters were studied and the optimization is performed using Matrix Laboratory (MATLAB).**

Index Terms—**Critical Path Method, Genetic Algorithm, Meta-heuristic, Resource-constraint Project Scheduling Problems.**

I. INTRODUCTION

Resource Constraint Project Scheduling (RCPS) is important to overcome the time lag and cost increase. Construction industry is a very fast growing industry and hence it is necessary to settle the disputes regarding resources. Resource allocation is important for reducing the time lag and reducing the cost estimate. With the vast research in the scheduling field different project planning and scheduling methods were developed. The Operational Research (OR) approach has put forward two major planning techniques: Critical Path Method (CPM) and Program Evaluation and review Technique (PERT). The critical path method CPM has been widely used for planning and controlling project schedules since the 1970s. The basic CPM theory assumes unlimited resources for a project. This assumption is not valid in most practical situations, in which there is a limit on the amount of resources available, particularly when resources are shared by multiple activities or even several projects [17].The CPM and PERT do not take into account about resource constraints and hence are not good enough for scheduling. RCPS problems are analyzed using algorithms to bring a harmony between time and cost trade off. In spite of

Manuscript received March, 2015.

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several meta-heuristic algorithms, adaptive method like genetic algorithm is widely used to solve search and optimization problems. Genetic algorithm is a method for solving optimization problems that is based on natural selection, the process that drives biological evolution.

The primary aim of this research is to develop a genetic algorithm optimization approach to schedule project activities and therefore to minimize the total duration of the projects scheduled already in Microsoft Office Project (MSP).To maximize the net present value of the cash flow in the project or to minimize the number of products that are delivered late and to determine the overall performance of plan and schedule using algorithm. This paper highlights the need and scope for research in this field of optimization. A general outlook about resource-constrained project scheduling is given along with that it reviews the optimization techniques, including classical and heuristic search, especially the GAs optimization techniques. It also provides a survey of studies in the field of optimizing the schedule of resource-constrained construction projects and finds the application and implementation of the GAs to various RCPSP projects.

II. RESOURCE-CONSTRAINED PROJECT SCHEDULING PROBLEMS (RCPSP)

Every project schedule has its own precedence constraints, which means that each activity can be processed when all its predecessors are finished. In general the purpose of project scheduler is to minimize its completion time or makespan, subject to precedence constraints. A more general version assumes that to develop one or more activities, resources such as tools, equipment, machines, or human resources are needed. Each resource has limited capacity; consequently at a certain moments one activity may not begin their processing due to resource constraints even if all their predecessors are finished, [3]. This type of problems is called RCPSP which involves assigning jobs or tasks to a resource or a set of resources with limited capacity in order to meet some predefined objective, [28]. The problem consists of finding a schedule of minimal duration by assigning a start time to each activity such that the precedence relations and the resource availabilities are respected.

Resources management is one of the most important aspects of construction project management in today's economy because the construction industry is resource intensive and the costs of construction resources have steadily risen over the last several decades. Often the project planner utilizes the time and precedence based schedule as a basis for the management of resources for the project [21]. The construction manager must develop a plan of action for

directing and controlling resources of workers, machines and materials in coordinated and timely manner in order to deliver a project within the frame of limited funding and time. The crucial factor in successful implementation of a construction project not only depends on the quality & quantity of work, but also largely depends on availability of resources. Each activity is allocated with a specific resource and must be completed within the time limit, otherwise it may adversely affect the overall duration of the project. The time required may be determined by dividing the productivity associated with the resources used on the activity into the defined quantity of work for the activity. The best combination of resources to use for performing a construction activity is based on contractor's ability to identify the interdependencies of the various resources [23]. Meta-heuristic algorithm is used because they generally perform better than simple heuristics making a higher level search in the solution space for the results.

III. META-HEURISTIC ALGORITHMS

Solution methods that orchestrate an interaction between local improvement procedures and higher level strategies to create a process capable of escaping from local optima and performing a robust search of solution space is called a meta-heuristic approach. This approach is done to the RCPSPs and projects are scheduled using algorithms. There are several meta-heuristic methods namely Particle Swarms, Ant Colony, Genetic Algorithms, Memetic Algorithms, Cellular Automata, Immune Systems, Simulated Annealing, Tabu Search, Greedy Randomized Adaptive Search Procedure, Variable Neighbourhood Search, Scatter Search. The two most noticeable advantages of genetic algorithms over traditional optimization algorithms are: the ability of dealing with complex problems and parallelism. Genetic algorithms can deal with various types of optimization whether the fitness function is stationary or non-stationary, linear or non-linear, continuous or discontinuous, or with random noise.

IV. GENETIC ALGORITHM (GA)

Genetic algorithm is a type of optimization algorithm, which is used to find the optimal solution(s) to a given computational problem that maximizes or minimizes a particular function. Genetic algorithms represent one branch of study called evolutionary computation. They imitate the biological processes of reproduction and natural selection to solve for the 'fittest' solutions. This optimization technique allows one to set the level of randomization and the level of control. These algorithms are found to be far more powerful and efficient than random search and exhaustive search algorithms. This feature allows them to find solutions to problems overcoming problems such as lack of continuity, derivatives, linearity, or other features. The main operators of genetic algorithm are:

1) Selection-During each successive generation, a proportion of the existing is selected to breed a new generation. They are selected according to their fitness. The better the chromosomes are, the more chances to be selected they have.
2) Crossover- It is the process of taking two parent solutions and producing from them a child. After the selection process, the population is enriched with better individuals makes clones of good strings but does not creak new ones. Crossover

operator is applied to the mating pool that it creates a better offspring.
3) Mutation- It is the process of randomly changing the genes of the individual parents. It operates independently on each individual. Mutation prevents the algorithm to be trapped in a local minimum [24].

V. RCPS PROBLEMS

A. Problem 1-(8 Activities)

The following problem was introduced by Toklu (2002). Toklu applied genetic algorithms to construction scheduling with or without resource, applying it to eight activities project problem. A simplified breakdown of the works necessary for construction of a bridge is considered to yield the activities shown in table I, where the precedence relations and durations are presented.

Table I. Precedence relations and durations of problem 1[24]

*A-Activity, P-Precedence, D-Duration, R-Resource usage

B. Problem 2-(12 Activities)

A construction project with twelve activities is considered in this problem. A simplified breakdown of the activities of

A	DESCRIPTION	P	D	R
A1	Excavation at pier A	-	15	R_1
A2	Pier works A	A1	20	R_2
B1	Excavation at pier B	-	10	R_1
B2	Pier works B	B1	30	R_2
CI	Excavation at pier C	-	27	R_1
C2	Pier works C	C1	30	R_2
D1	Deck AB	A2,B2	24	R_3
D2	Deck BC	B2,C2	18	R_3

problem 2 is shown in table II, where the precedence relations and durations are presented and the resource availability is given in table II.

C. PROBLEM 3- Green's Shopping Mall

The Green's shopping mall project is an ongoing project which is a one storey building of 10 shops together at Pallikunnu, Kannur, Kerala. It is totally 1251 sq ft. The precedence relations, durations and resource usage are given in table III.

Table II. Precedence relations and durations of problem 2[24]

A	P	D	R
A	-	11	R_1
B	-	14	R_1, R_4

C	-	15	R_1
D	A	10	R_2
E	A	10	R_2
F	B,C	14	R_2
G	D	13	R_4
H	E	12	R_3
I	E	7	R_3
J	G	8	R_4
K	H	8	R_4
L	I,F	5	$2R_1,R_3$
M	J,K,L	6	$2R_2,R_4,3R_5$

Table III. Precedence relations, durations and resource usage of Green's shopping mall Project

A	P	D	R	
			R1	R2
Site Work	NIL	2	3.53	NIL
Foundation	A	8	15.94	565.73
Random Rubble Masonry	B	15	39.09	83.38
Ground Floor Superstructure	C	28	80.12	70.29
Ground Floor Roof	D	26	26.21	38.2
Stairs	E	4	12.87	20.53
First Floor Superstructure	E	21	62.18	80.09
First Floor Roof	F,G	24	38.63	40.12
Wood	H	20	15.1	205.08
Plumbing	H	6	19.03	242
Plastering Ground Floor	J	10	23.36	13.37
Plastering First Floor	J	15	30.42	17.41
Flooring	K	41	31.52	126.92
Painting for Plastering	L,M	22	15.32	26.37
Painting for Wood Work	N	2	6.34	15.13
Painting for Steel Work	O	2	1.49	5.72

Table IV. Precedence relations, durations and resource usage of Tendering Process and Building of a Foundation

A	P	D	R		
			R1	R2	R3
Contract agreements	NIL	1	7	NIL	NIL
Documentation and revision	A	41.5	7	NIL	NIL
Bids and contracts	B	16	4	NIL	NIL
Review bids	C	15	3	NIL	NIL
Grading and building permits	B	26.5	8	2	5
Site work	E	8	1	4	NIL
Foundation	F	27.5	2	10	327.81

VI. RESULTS AND DISCUSSIONS

The RCPSP problems under consideration were analyzed using Critical path method, Microsoft Project and Genetic Algorithm. The optimization is performed by varying duration for each activity in the critical path. The results from the above methods are compared and GA results are found to be more feasible. Critical Path method (CPM) is a step-by-step project management technique for process planning that defines critical and non-critical tasks with the goal of preventing time-frame problems. Microsoft Project is a project management software program developed and sold by Microsoft, which is designed to assist a project manager in developing a plan, assigning resources to tasks, tracking progress, managing the budget, and analyzing work loads. In the field of artificial intelligence, a genetic algorithm (GA) is a search heuristic that mimics the process of natural selection. This meta-heuristic is routinely used to generate useful solutions to optimization and search problems. The duration of the RCPSP under study based on different methods are presented in the table V.

Table V. Comparison of durations of RCPSP using different methods

Sl. No	PROJECT	DURATION (days)		
		CPM	MSP	GA
1	Sample 1	75	114	108
2	Sample 2	48	60	55
3	Greens shopping mall	207	246	244
4	Foundation process	104	135	123

D. PROBLEM 4- Tendering Process and Building of a Foundation

Tendering Process and Building of a Foundation is located at Parassinikadavu, Kannur, Kerala which is a 14 cu.ft structure and the precedence, duration and resource usage of the project is given in Table IV
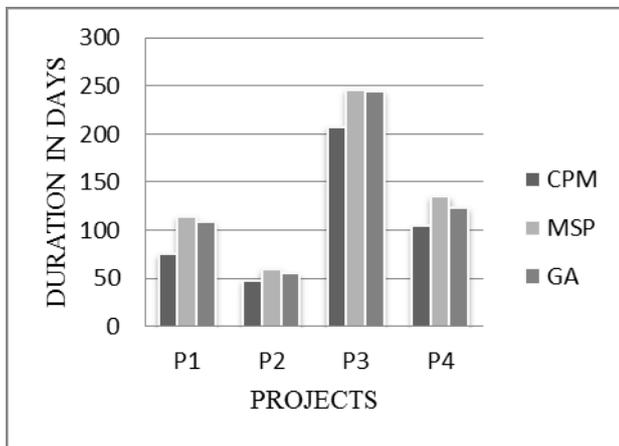
Fig.1- Graph representation of comparison between methods.

VII. CONCLUSION

The project scheduling under resource constraints problem is one of the most intractable problems in Operations Research and it has recently become a popular area for the latest optimization techniques, including virtually all local search paradigms. The importance of project scheduling under resource constraints problems will increase in future as the limitation on resources will be tighter, hence we expect to see better portion of the project scheduling literature developing around the various project scheduling under resource constraints problems. The presented meta-heuristic algorithm of optimization complements the traditional CPM approach and MSP software for scheduling by optimizing project schedule as it performs resource constraint project scheduling. The project results show that the algorithm is able to find the best known solutions from the problems space. Further researches have to be done regarding the early convergence of GA and also in handling highly complex problem.

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