Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 69 (2014) 725 – 734

Procedia Engineering

www.elsevier.com/locate/procedia

24th DAAAM International Symposium on Intelligent Manufacturing and Automation, 2013

Resource Constrained Multi-Project Scheduling with Priority Rules & Analytic Hierarchy Process

Amol Singh*

IIM Rohtak, Rohtak – 124001 Haryana India

Abstract

This paper presents a hybrid algorithm that integrates the project priority (or criticality) with project schedule development for multi-project scheduling problem under resource constrainedsituation. The objective here is to minimize the project make-span as well as the penalty cost when some projects carry higher priority. Since the problem is NP hard, we solve this problem by integrating the project priority with the activity priority. The project schedule is generated using a hybrid algorithm based on priority rules and AHP. The proposed algorithm is demonstrated to be better than existing priority rules. The effectiveness of the proposed algorithm is validated with computational results.

Selection and peer-review under responsibility of DAAAM International Vienna

Keywords: project management; hybrid algorithm; resource constrained projects; scheduling

1. Introduction

Project management is asystem of managing nine knowledge areas pertaining to projects' time, cost, scope, quality, risk, procurement, human resource, communication, and integration. Integration of these nine knowledge areas makes the project management a complex decision making process.A project manager always has a pressure to satisfy the demand of its stakeholders in terms of cost, quality, time and scope. A typical project management problem consists of planning and scheduling decisions. In theplanning process, project manager distributes the total project work into manageable activities. The manager estimatesdemand forvariety of resources and time of all the activities involved in the project. Further, he develops the Gantt chart and assigns the resources to the project

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000 .
E-mail address: amolasingh2007@rediffmail.com

Selection and peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2014.03.048

activities to generate the resource profiles.He performs the required resource levelingby contracting, subcontracting and allocating overtime resources.Project scheduling is the process of allocation of the given resources to the project activities to determine the start time and finish time of each activity. If resources are adequate but the demand varies widely over the life of the project, it may be desirable to even out resource demand by delaying noncritical activities (using slack) to lower peak demand and thus, increase the resource utilization. This process is known as resource leveling or smoothing. On the other hand, if resources are not adequate to meet the peak demands, the late start of some of the activities must be delayed, and the duration of the project may be increased. This process is known as resource constrained scheduling.

Most of the projects handling industries have limited resources and if they have multiple projects and each project has a priority level then it makes the solution process more complex. The allocation of scare resources to multiple projects, where each project has different priority level, is the major objective of the problem. This problem has to be solvedby considering several compromises to get the desired level of near optimality.

In this paper, a new hybrid algorithm approach has been proposed to solve the resource constrained multi-project scheduling problem under the priority level of projects (RCMPS). The remainder of the paper is organizedas follow. Section 2 presents a literature review on project scheduling and identifies research issues which form the basis for the problem formulation. Section 3 describes the problem and presents the conceptual model.Section 4 describesthe approach to solve the RCMPS problem.Section 5 reports the case study and computational experiments. Section 6 concludes the study and indicates the scope for future research.

Nomenclature

N number of projects
T variety of resources used by multiple projects
O_n number of activities in project *n* where, n = { 1, 2 …….N}.
$K_n$number of resource types required by project n where n = { 1, 2 …….N}.
$C_n$criticality index of project *n* where, n = { 1, 2 …….N}.
R_{kon}number of K type of resource required to accomplish the o^{th}activity of Project *n*
K_{on}type of resource required to accomplish the work of activity o of project n
GA genetic algorithm
FCFS first come first serve
MINSLKminimum slack first
RCMPS resource constrained multiple project schedule
MAXTWK maximum total work content
SASP shortest activity from the shortest project
MINLFT minimum latest finish time
RCMPS resource constrained multi-project problem

2. Literature review

Scheduling and allocation of resources for multiple projects is a non-polynomial (NP) hard problem and more difficult than a single project [1]. Traditional optimization methods have been used in the literature to solve the multi project scheduling problems.In a pioneering work in this category, Pritsker et al. [2],reported a zero-one programming approach to solve the multi-project scheduling problem. Mohanty and Siddiq [3] investigated the problem by assigning the due dates to the multiple projects. They used an integer programming for generating the schedule and a simulation mechanism for testing the heuristic rules to choose the best schedule. Deckro [4] formulated the multiproject scheduling problem as a general integer programming model and used a decomposition approach to solve the large size of problems. Jolayemi [5] used integer programming approach for project scheduling and considered penalty and reward function in the formulation of objective function.

A common feature of these studies is that project scheduling problems of small sizes can be solved by the traditional optimization techniques. However, as the number of projects and size of the projectin terms of number of activities increase, the problem becomes more complex.Further, the complexity increases when variety of resources is considered.In this context,it is not feasible to developthe projects' schedules by using the traditional optimization techniques. The benefit of traditional optimization techniques cannot be utilized for generating the schedule of multiple projects simultaneously. Accordingly, researchers have developed several heuristic and Meta heuristic methods for multi project scheduling. Presently,several efforts are being made to find out the more efficient algorithms to generate the multi-project schedules [6]. These efforts are being made to increase the efficiency of the heuristics methods, extending the scope of the problems with heuristic methods and developing new methods with inferior computation time [7]. Some researchers have used artificial intelligent techniques to generate the resource constrained project schedules [8]. However, as the number and size of the projects increase, the computational efficiency of these methods also decreases. Kim et al. [9] applied a combined genetic algorithm to generate the schedule of the multi- projects scheduling problem. They minimized the total project completion time and any penalties for a general delay. Kumanan, et al. [10] used GA with heuristic method for generating the schedule of multi-projects and the performance of the generated schedule was measured against project completion time. Damak et al. [11] also used GA with a local search strategy to generate the schedule of multiple projects with resource constraints and project delay was considered as the performance measure to measure the performance of the schedule. Chen [12] reported that there is a need to develop efficient methods to enhance the quality and computational efficiency of the solutions of resource constrained multiple project scheduling problems.

The key challenge for all project managers is to meet the pressure from project sponsors to complete the project within the deadline and under approved budget. In this situation, it is critically important to find out the solution of multiple project resource constrained scheduling problems. Project managers have to pass on the instructions to the project team members to complete their task in a timely manner to meet the deadline of the projects. In this context, priority rules are the most efficient methods to generate the schedules rapidly and are very simple in application. Several priority rules have been reported in the literature.Vidya et al. [13] provide a succinct review of multi project scheduling techniques. Fendley [14] used multiprojects with three and five projects and considered three efficiency measurements in the computational analysis, namely, project slippage, resource utilization, and in-process inventory. They concluded that the priority rule MINSLK showedmostefficient with the three response variables. Kurtulus and Davis [15] designed multi-project scheduling problem where projects had 34 to 63 activities and resource requirement for each activity was between 2 and 6 units. They devised six new priority rules and showed MAXTWK and SASP as the best algorithms to schedule multi-projects when the objective was to minimize the mean project delays,which were measured in relation to the unconstrained critical path duration. Kurtulus and Narula [16] modified the earlier rules proposedby Kurtulus and Davis [15]by adding the penalties due to project delay. They investigated multi-project scheduling problem with three projects in which the number of activities varied between 24 and 33 and 50 – 60 for small-sized and large-sized problems, respectively. They studied four new priority rules, namely, Maximum Duration and Penalty, Maximum Penalty, Maximum Total Duration Penalty, and simultaneously Slack and Penalty. They concluded that the priority rule Maximum Penalty was the best algorithm to minimize the sum of the project weighted delays.

Dumond and Mabert [17] studied the problem of assigning due dates to the projects in a multi-project environment. In their work, each project was assigned 6 to 49 activities with the resource requirements comprising one to three types of resources. They considered five resource allocation heuristics. They reported that the priority rule FCFS with the strategy Scheduled Finish Time Due Date rule was the best algorithm for minimizing the mean completion time, the mean lateness, the standard deviation of lateness and minimizing the total tardiness. Lawrence and Morton [18] studied the due date setting problem of scheduling multiple resource-constrained projects with the objective of minimizing weighted tardiness costs. They developedsome new policies and tested these policies against a number of dispatching scheduling rules reported in the literature. Christodoulou [19]optimise the allocation of resources by use of entropy metric.Shankar and Nagi [20] proposed a two-stage hierarchical approach consisting of planning and scheduling stages. They usedlinear programing for the planning stage and simulated annealing forthe resource schedule stage.

Lova et al. [21] developed a multi-criteria heuristic that consisted of several algorithms based on feasible schedules. They showed that the method improved the feasibility of the multi-project schedule obtained from heuristic methods based on the priority rules, MAXTWK and MINLFT, and also the project management software – Microsoft Project, Time Line, and Project Scheduler.Dalfard and Ranjbar[22] used simulating annealing approach for generating the schedule of resource constrainedmultiple project problems.The computational results were compared with 20 existed priority rules in terms of project completion time. They showed that the simulated annealing approach yielded better results than priority rules. Saleru [23] developed the resource constrained project schedule of a software industry by using the project management software (primavera). Zheng et al. [24] proposed an algorithm for generating the schedule of resource constrained multiple project problems. They investigated the robustness of the algorithm in terms of various project parameters such as order strength, resource constraint and uncertainty level. Their results demonstrated the effectiveness of the solution algorithm and showed that these three parameters indeed have evident impacts on the robustness and make-span of projects.

Observations and research issues

From the literature survey,a couple of observations can be made in order to devisethe problem formulation in the present study. Firstly, most of the reported projects scheduling methods are applicable in scheduling of all activities of a single project. There is a need for research on scheduling of multiple projects [25]. Secondly, scheduling and allocation of resources for multiple projects is more difficult than single project. Thus, there is a need to develop more efficient algorithms in terms of computation time and quality of solutions to generate the multiple project schedules for complex problems. Thirdly, most of the researchers have considered single variety of resource for generating the schedules in multi project environment. However, in real life problemsan activity needs more than one resource. Thus, there is a scope of research on multi-project scheduling by considering a variety of resources.

For addressing these research issues, three major tasks are outlined. Firstly, a complex multi project scheduling problem with resource constrainedenvironment is considered. The considered multi project with resource constrained environment is briefly described in section 3. The performance of multi-project with resource constrainedschedule is enhanced in terms of customer requirement by integrating the project criticality index with the activity priority index. Secondly, an efficient hybrid algorithm has been developed for generating the schedule of multi-project resource constrained problem. This algorithm integrates the project criticality index with the activity priority. Thirdly, in order to address the real requirement of the projects, a variety of resources are considered for each activity during the schedule development.

3. Problem description and projected model formulation

Project schedule is the base line plan for monitoring and controlling the project activities and it is the main tool for project management. In recent years, projects have become increasingly pervasive in companies. In the global business environment thedevelopment of new machinery and equipment's, new production processes and computer support systems leads to the development of new products, services, and processes.This unique work is accomplished through projects.Companieshaveseveral projects in their portfolio,some projects carry higher priority than others or a customer sends in a request to complete his project early. In the present study, this aspect is considered and the project priorities areintegrated with the schedule development activity under a variety of resource constrainedconditions.The problem consists of a set of 'N'numberof projects, where,n^{th} project comprises of 'O_n'number of activities, where, $n = \{1, 2 \ldots\ldots N\}$. Each project has a priority level or criticality index (C_n), where,$n = \{ 1, 2 \ldots\ldots N\}$. These activities requireK_{on} number of resource types, where,$o = \{1, 2 \ldots\ldots O\}$ and where, $n = \{ 1, 2 \ldots\ldots N\}$.The activities are interrelated by two types of constraints including precedence constraint, where successor activity forces the completion of its predecessor activity before its start and resource constraints, where the processing of the activity is subjected to the availability of resource with limited capacity. Activity o_n, while being processed requires R_{kon}units of resource K,where, $k = \{1, 2 \ldots\ldots K_{on}\}$, $o = \{1, 2 \ldots\ldots On\}$ and $n = \{1, 2 \ldots\ldots N\}$. All resource types have a limited availability at any given point of time.The main objective of the present study on resource constrained multi-project scheduling problem is to determine the start time and completion time of all activities (project schedule) in order to improve some performance measures underlimited resource availability condition, criticality index of each project,and precedence constraints.The make-span and cost deviation is considered as the performance measures during the performance evaluation of the multi-project schedule.

4. Methodology

The priority index of the projects is determined by using the analytic hierarchy process (AHP). This process was devised by Sathy [26] as a mathematical procedure to assign weights to 'N'projects using a scheme of pairwise comparisons.The steps of this procedure are described as follow:

Step 1: Analytic hierarchy process **(**AHP) initially divides a complex multicriteria decision-making problem into a hierarchy of interrelated decision criteria, and decision alternatives. The criteria and alternatives are arranged in a hierarchical structure similar to a family tree with decision alternatives at the bottom and criteria above the bottom level as shown in Fig 1.

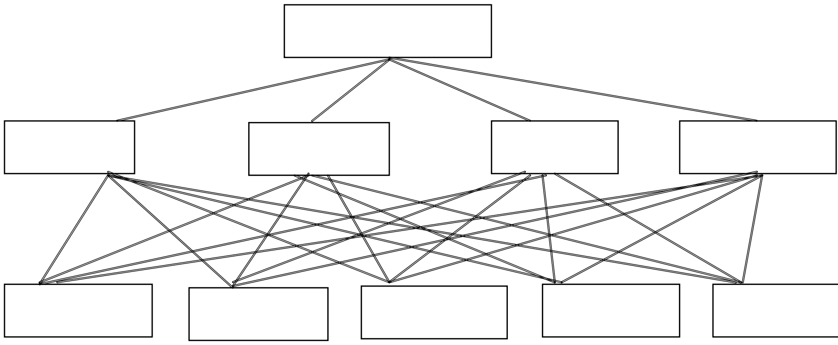


Fig. 1. AHP hierarchy.

Step 2: Acomparison among the alternatives and criteria is then made. Once the problem is decomposed and the hierarchy is constructed, prioritization procedure starts in order to determine the relative importance of the criteria within each level. The pairwise judgment starts from the second level and finishes at the lowest level. In each level, the criteria are compared pairwise according to their levels of influence and based on the specified criteria at the higher level.The pairwise comparison at each level is preceded by a conversion process of intangible into number by using a scale. The numerical values of for each project with respect to a criterion are shown in Table 1.

Table 1. Values of m performance measures for n projectsafter converting intangibles into numbers.

Projects	Criteria		
	C_1	C_2	C_m
P_1	A_{11}	A_{12}	A_{1N}
P_2	A_{21}	A_{22}	C_{2N}
P_N	A_{N1}	A_{N2}	A_{NN}

The result of the pairwise comparison on ‘*n*’ alternatives (projects) with respect to each considered criteria is summarized in an (*n, n*) evaluation matrix as shown in Table 2. It may be noted that if the criterion is cost criterion then reciprocal of each value is considered for pairwise comparison as given in the Table below.

Table 2. Pairwise comparison matrix or normalization matrix.

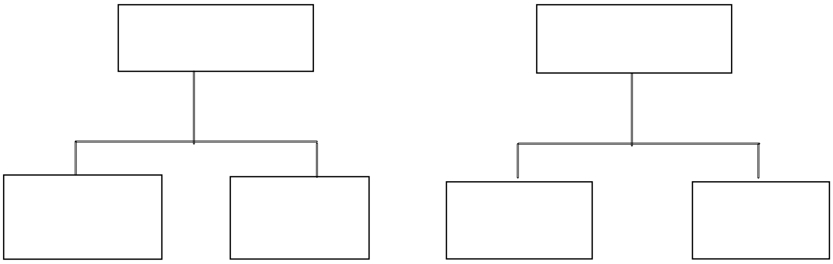
	P_1	P_2	P_m
P_1	A_{11}/A_{11}	A_{12}/A_{22}	A_{1N}/A_{NN}
P_2	A_{21}/A_{11}	$A_{22}A_{22}$	C_{2N}/A_{NN}
P_N	A_{N1}/A_{11}	A_{N2}/A_{22}	A_{NN}/A_{NN}

Step 3: Compute the weightage decision matrix. The column sum of Table 2 is computed and each value of the column is divided by its column sum. This matrix is known as weightage decision matrix. Once the

weightage decision matrix is determined, the row wise average is computed of the weightage decision matrix. These values denote the weights of the '*N'* projects with respect to the considered criteria.

Step 4: Repeat step 2 and 3 for each criteria and compute the weights of the projects with respect to all considered criteria.Similarly, compute the weights of criteria by using the step 2 and 3.

Step 5: Compute the priority index of each project. Illustratively, if 'W_u' and 'W_g' are the weights of urgency and growth, (W_{p1u},W_{p2u}) and (W_{p1g}, W_{p1g}) are the weights of project 1 and 2 with respect to urgency and growth. The priority index of project 1 and 2 is computed as shown by equations 1 and 2.



Priority index of project 1 = $(W_u \times W_{p1u}) + (W_g \times W_{p1g})$ (1)

Priority index of project 2 = $(W_u \times W_{p1u}) + (W_g \times W_{p1g})$**(2)**

It may be noted that the project manager can use the weights of the criteria as per the urgency of the projects or customer requirements during the schedule development.

Step 6: The priority index or criticality index of each projects computed in step 5 is used in combination with the activitypriority index computed by thebest reported dispatching rule to decide the priority of the project activities for resource allocations. In this study,four best reported rules i. e. *EDDF*, *MINSLK*, *MAXSP*, *MINWCS* are considered for generating the schedule of multi project resource constrained problems.

Step 7: The performance of the project schedule is measured in terms of the make-span. Make-span of a project is the difference between the completion date of last activity and start date of the project.The overall make-span of multi-projects is the maximum make-span of the considered projects. In addition the performance of the multi-project schedule is also measured in terms of total cost deviation in relation to the unconstrained critical path duration. The total cost deviation is computed by using the following relation:

$$\delta C = [\sum_{i=1}^{i=N} \delta(MS) \times pc] + [overall\delta(MS) \times ic] \quad (3)$$

Where, δC = total cost deviation, $\delta(MS)$ = deviation in the make-span of a project, pc = penalty cost, *overall(MS)* = overall deviation in make-span of multi-projects,ic = indirect cost.

5. Case study

A projectCompanyhas five projects includingP_1, P_2, P_3, P_4 and P_5 in his portfolio and wants to develop the schedule of these projects. These five projects were selected by using the four criteria including urgency of the project, net present value (*NPV*), risk, and growth. The performance of these projects in relation withfour criteria is given in Table 3.Project manager has been asked to develop the schedule of these projects by using the project priority index or project criticality factor. The project manager develops the work breakdown structure of the projects and estimates the activities and their predecessors,activity duration, and resource requirement of each project. This information of all the projects is shown in Tables 4 to 8. The company has 35 resources of each variety.

Table 3. Project performance of different criteria.

Projects	Criteria			
	Urgency	NPV	Risk	Growth
P_1	Very High	40	Low	Good
P_2	High	30	Low	Good
P_3	High	50	High	Excellent
P_4	Low	60	Medium	Poor
P_5	Low	20	Medium	Good

Table 4. Activity duration, predecessor and resource requirement for project 1.

Activity	Predecessor	Duration	Resource 1	Resource 2	Resource 3	Resource 4
1	-	0	0	0	0	0
2	1	1	1	9	6	10
3	1	3	3	7	0	7
4	2,3	4	6	8	2	1
5	2,3	5	7	5	8	2
6	4,5	2	8	4	0	2
7	4,5	2	6	0	8	9
8	6,7	0	0	0	0	0

Table 5. Activity duration, predecessor and resource requirement for project 2.

Activity	Predecessor	Duration	Resource 1	Resource 2	Resource 3	Resource 4
1	-	0	0	0	0	0
2	1	5	10	3	7	10
3	1	2	8	6	8	2
4	1	1	6	0	3	0
5	2,3	5	8	0	0	10
6	4,5	2	10	9	9	10
7	2,3,4	4	4	2	6	2
8	6,7	0	0	0	0	0

Table 6. Activity duration, predecessor and resource requirement for project 3.

Activity	Predecessor	Duration	Resource 1	Resource 2	Resource 3	Resource 4
1	-	0	0	0	0	0
2	1	4	10	5	3	0
3	1	4	0	3	0	6
4	1	2	0	8	3	6
5	2,3	3	9	5	2	10
6	2,3,4	4	5	0	0	4

7	4,5	5	2	6	0	0
8	6,7	0	0	0	0	0

Table 7. Activity duration, predecessor and resource requirement for project 4.

Activity	Predecessor	Duration	Resource 1	Resource 2	Resource 3	Resource 4
1	-	0	0	0	0	0
2	1	2	4	8	9	0
3	1	3	0	4	1	9
4	1	2	9	2	7	0
5	2,4	3	0	7	3	0
6	3,5	1	8	9	6	6
7	2,3,4	3	0	1	0	3
8	6,7	0	0	0	0	0

Table 8. Activity duration, predecessor and resource requirement for project 5.

Activity	Predecessor	Duration	Resource 1	Resource 2	Resource 3	Resource 4
1	-	0	0	0	0	0
2	1	2	0	8	0	0
3	1	1	0	2	8	0
4	2,3	1	0	0	8	3
5	2,3	5	2	8	0	0
6	4,5	5	0	1	0	0
7	4,5	1	0	4	0	7
8	6,7	0	0	0	0	0

The priority index of the projects is computed by using steps 1to 5 ofproposed methodology given in section4. The computed projects priorities orcriticality index under different weights of the criterion is given in table 9.

Table 9. Projects criticality index under different weightage of criteria.

Projects	Equal weights	Urgency =0.7, NPV = 0.1, Risk = 0.1, Growth = 0.1	Urgency =0.1, NPV = 0.7, Risk = 0.1, Growth = 0.1	Urgency =0.1, NPV = 0.1, Risk = 0.7, Growth = 0.1	Urgency =0.1, NPV = 0.1, Risk = 0.1, Growth = 0.7
P_1	0.236	0.271	0.214	0.251	0.207
P_2	0.208	0.225	0.173	0.24	0.196
P_3	0.232	0.234	0.243	0.171	0.28
P_4	0.179	0.142	0.252	0.176	0.147
P_5	0.145	0.128	0.118	0.162	0.17

The five levels of projectspriorities given in Table 9 are used to develop the five set of schedules as discussed in step 6 of section 4. These five set of schedules are shown in Fig.2. During the performance analysis of the proposed algorithm, it is considered that penalty cost of urgent project and rest of the projects are $5000 and $1000 per day respectively. The daily operating expenses or indirect cost of each project is $1000 per day. The penalty cost of a project is computed by the multiplication of deviation in make-span of a projectto the penalty cost. The deviation in project make-span is measured in relation to the unconstrained critical path duration. The overall deviation of the projects make-span is computed and is multiplied by the operating expenses per day for computing the overall deviation in the indirect cost. These costs are summed up and given in the last row of Table 10. The data given in Table 10 validate the effectiveness of the proposed algorithm.

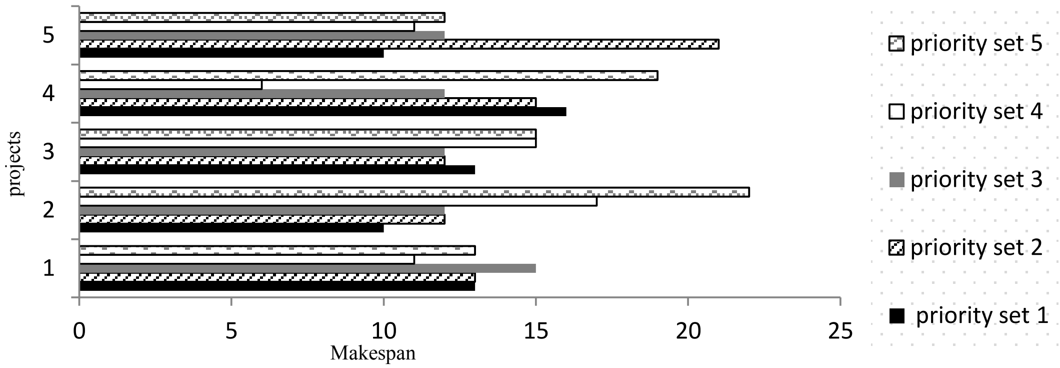


Fig. 2. Make span of project schedules with five set of project priorities.

Table 10. Comparative analysis of the proposed algorithm (WPA) with the best priority rule (WBPR) by considering deviation in cost.

Project	Cost		Cost		Cost		Cost	
	WBPR	WPA	WBPR	WPA	WBPR	WPA	WBPR	WPA
P1	15000	0	3000	3000	3000	6000	3000	0
P2	1000	0	5000	0	1000	3000	1000	4000
P3	3000	0	3000	0	15000	00	3000	0
P4	5000	9000	5000	9000	5000	0	5000	5000
P5	1000	10000	5000	3000	1000	7000	5000	0
Over all Make-span	1000	5000	500	2500	500	3500	500	5500
Total cost	25500+	24000*	21500+	17500*	25500+	19500*	17500+	14500*

* Penalty cost and indirect cost obtained by the proposed method, + Penalty cost and indirect cost obtained by the existed priority rule

6. Conclusion and future research directions

In this study, an attempt was made to integrate the project priorities with the project schedule development. Ahybrid algorithm was developed to accomplish this task. The reported algorithm is a new method for generating the schedule of any multi-project resource constrained scheduling problem where, each project has a defined criticality. The proposed method was validated with a case studyunder various scenarios. Experimental results were compared with existingpriority dispatching rules. Experimental results showed the superiority of the proposed method with the existing priority dispatching rules under different operating conditions.

In real project management environment, a penalty is imposed if a project completes after its due date. Some projects carry higher penalty than others. In this context, project manager can make a tradeoff among the projects penalties and can develop the cost effective project schedule, which satisfies the customer requirements. In this context, the proposed algorithm would be beneficial for project manager's to deal with these conditions.In the future, research could explore the possibility of integrating other knowledge areas including risk management and procurement management with the project schedule development.

References

[1] Garey, M. R., Johnson, D. S., Computers and intractability a guide to the theory of NP completeness, W. H. Freeman and Company, New York, 1979.

[2] Pritsker, A., Allan, B., Watters, L. J., Wolfe, P. M., Multiproject scheduling with limited resources: A zero-one programmingapproach, Management Science, 16, (1969), 93–- 108.

[3] Mohanthy, R. P., Siddiq M. K., Multiple projects multiple resources-constrained scheduling: Some studies. International Journal of Production Research, 27 (1989), 261–280.

[4] Deckro, R. F., Winkofsky, E. P., Hebert, J. E., Gagnon, R., A decomposition approach to multi-project scheduling, European Journal of Operational Research, 51, (1991), 110– 118.

[5] Jolayemi, J. K., scheduling of projects under penalty and reward arrangements: A mixed integer programming model and its varients, Academy of Information and Management Science Journal, 15, (2012), 29-52.

[6] Gawiejnowicz, S., Lin, B.M.T., Scheduling time-dependent jobs under mixed deterioration, Applied Mathematics and Computation, 216, (2010), 438-447.

[7] Rezaie, K., Ostadi , B. A., Mathematical model for optimal and phased implementation of flexible manufacturing systems, Applied Mathematics and Computation, 184, (2007), 729-736.

[8] Ranjbar, M., Kianfar, F., Shadrokh, S., Solving the resource availability cost problem in project scheduling by path relinking and genetic algorithm., Applied Mathematics and Computation, 196, (2008), 879–888.

[9] Kim, K.W., Yun, Y.S., Yoon, J.M., Gend, M., Yamazaki, G., Hybrid genetic algorithm with adaptive abilities for resource-constrained multiple project scheduling, Computers & Industrial Engineering, 56, (2005), 143-160.

[10] Kumanan, S., Jegan Jose, G., Raja, K., Multi-project scheduling using a heuristic and a genetic algorithm, International Journal of Advanced Manufacturing Technology, 31, (2006), 360-366.

[11] Damak, N. Jarboui, B., Siarry, P., Loukil, T., Differential evolution for solving multi-mode resource constraint scheduling problems, Computer and Operations research, 36, (2009), 2653-2659.

[12] Chen, R. M., Reducing network and computation complexities in neural based real-time scheduling scheme, Applied Mathematics and Computation, 217, (2011), 6379-6389.

[13] Vidya, S. S., Suguna, M., Sharmila, D., A study on multi project resource constrained project Scheduling using Meta heuristic approach, International Journal of Computer Science and Mobile Computing, 2, (2013), 430 – 434.

[14] Fendley, L. G., Towards the development of a complete multi-project scheduling system, Journal of Industrial Engineering, 19, (1968), 505-515.

[15] Kurtulus, I. S., Davis, E. W., Multi-project scheduling: Categorization of heuristic rules Performance, Management Science, 28, (1982), 161-172.

[16]Kurtulus, I. S., Narula, S. C., Multi-project scheduling: Analysis of project performance, IIE Transactions, 17, (1985), 58-66.

[17] Dumond, j., Mabert, V. A., Evaluating project scheduling and due date assignment procedures: An experimental analysis, Management Science, 34, (1988), 101-118.

[18] Lawrence, S. R., Morton, T. E., Resource-constrained multi-project scheduling with tardy costs: Comparing myopic bottleneck and resource pricing heuristics, European Journal of Operational Research, 64, (1993), 168-187.

[19] Christodoulou, S.E., Tezias, E.S., Galaras, K.A., Resource-constrained scheduling of construction projects and simulation of the entropy impact on a project's duration and cost, International Journal of Project Organisation and Management, 4, (2012), 322 – 338.

[20] Shankar, V., Nagi, R., A flexible optimization approach to multi-resource, multi-project planning and scheduling, In Proceedings of 5th Industrial Engineering Research Conference, Minneapolis, MN, USA, 1996.

[21] Lova, A., Maroto, C., Tormos, P., A multicriteria heuristic method to improve resource allocation in multiproject scheduling, European Journal of Operational Research, 127, (2000), 408-424.

[22] Dalfard, V. M., Ranjbar, V., Multi project scheduling with resource constraints & priority rules by the use of simulated annealing algorithm, Technical Gazette, 19, (2012), 493-499.

[23] Saleru, C., Resource allocation in project management, International Journal of Economic Practices and theories, 2, (2012), 274-282.

[24] Zheng, Z., Shumin, L., Ze, G., Yueni, Z., Resource constraint multi project scheduling with priority and uncertain activity durations, International Journal of Computational intelligence, 6, (2013), 530-547.

[25] Erel, E., Ghosh, J. B., Customer order scheduling on a single machine with family setup times: complexity and algorithm, Applied Matthematics and Computation, 185 (2007) 11-18.

[26] Saaty, T. L., Analytical Hierarchy Process, McGraw Hill Company, NY, USA, 1980.