Review on Multimode Resource Constrained Project Scheduling Problem

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Abstract— **There are various project scheduling problems like single-mode resource constrained problem, multi-mode resource constrained scheduling problem, single-project and multi-project scheduling problem. Multimode Resource Constrained Project scheduling problem (MRCPSP) is NP-hard problem in which each activity has several non-preemptive execution modes. Each execution mode of an activity has a different resource requirement (renewable and non-renewable resource) and a related duration. On project scheduling problems with multiple execution modes, the genetic algorithm performed better than deterministic, bounded enumerative search methods. Various approaches and techniques have been applied for getting approximate optimized solution by some authors and scientists. These techniques have been discussed in this paper.**

Keywords- **Genetic Algorithm (GA), Multimode Resource Constrained Project scheduling problem (MRCPSP), Optimization, Heuristic Method, Local Search.**

I. INTRODUCTION

The multi-mode resource-constrained project scheduling problem (MRCPSP) is an extension of the single-mode resource-constrained project scheduling problem (SMRCPSP), within which each activity has several non-preemptive execution modes. Each execution mode of an activity has a different resource requirement and a related duration [1]. Tasks may have more than one mode of execution. Each execution mode has its own set of resource requirements and estimated duration. The objective is to find an assignment of modes to activities, as well as precedence and resource-feasible starting times of all activities such that the project duration (i.e., makespan) is minimized. The activities of a project have to be scheduled in order to minimize the project makespan. These activities are subject to precedence constraints and the limited availability of the resources. Moreover, each activity can be performed in one out of several modes, which consists in a different combination of resource requirements and duration. The problem type is known to be NP-hard and has been solved using various exact as well as (meta-) heuristic procedures. So many works has been done to solve the MRCPSP. The most common and successful approaches to solve the MRCPSP are those applying heuristics, metaheuristics and sampling schemas, given their practicability and effectiveness.

II. MULTIMODE RESOURCE CONSTRAINED PROJECT SCHEDULING PROBLEM

1) *Problem Description*

MRCPSP is a constraint satisfaction optimization problem (CSOP). According Lin-Yu Tseng and Shih-Chieh Chen [1] The problem involves a single project comprising of

– A set of non-dummy activities $J = \{1, 2 \ldots n\}$.
– *RR* and *NR* are the sets of renewable and nonrenewable resources, respectively.
– $EM_j = \{1, 2 \ldots M_j\}$ is the set of execution modes for activity *j*, where $j \in J$.

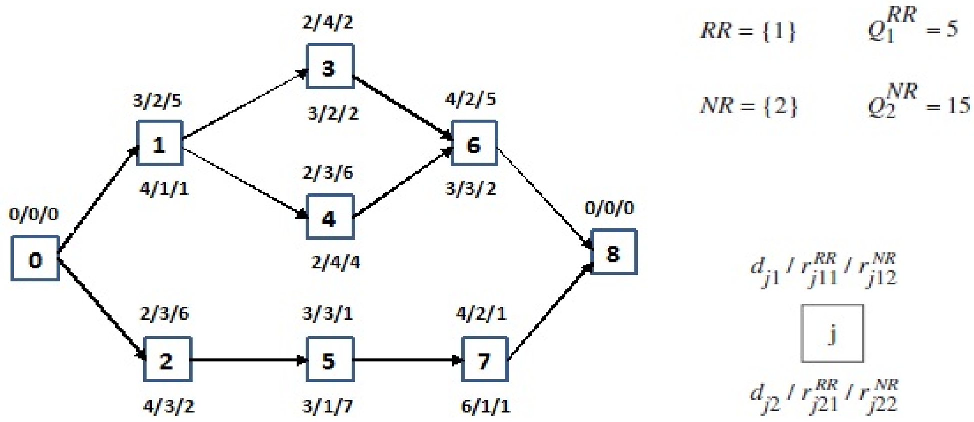

Fig. 1 Instance of Multimode Resource Constrained Project Scheduling Problem [1]

– A mode represents a combination of different resources and/or levels of resource requirements with a related duration.

– Different activity execution modes (m=1….Mj) requires different amounts or different types of resources (renewable and non-renewable) and represent alternative ways of realising an activity.

– The resource constraints are given such that for each $k \in RR$ the per-time-period availability is a constant quantity of renewable resources and for each $k \in NR$ the overall availability for the entire project is a constant quantity of non-renewable resources**.**

In this example, the project contains nine activities including two dummy activities; one renewable resource (RR) with a quantity of 5 units, and one non-renewable resource (NR) with a quantity of 15 units. The problem instance have a unique dummy start and finish activities, *j*=1 and *j*=*J*, each only performable in a single mode together with zero duration and zero resource requirement, respectively. For all other activities we assume that modes are sorted in the order of non-decreasing duration.

2) *Resource Constraints*

Resources may have additional constraints. Many resources include temporal restrictions that limit the periods of time when they can be used. For example, one team of machinists may be available only during the first shift. The constraints may be more complicated as well. Another team of machinists may be available during any shift at a higher labor rate and on the condition that they receive one shift off for every two shifts on.

Resources may be renewable or non-renewable. Renewable resources are the natural resources that can be remade or upgrade within short period of time. Renewable resources are available on a period-by-period basis, that is, the quantities available are renewed from period to period (hour, day, week, and month). The per-period availability is assumed constant. E. g., manpower, machines, fuel flow and space are renewable resources. Renewable resources are available each period without being depleted. Examples of renewable resources include labor and many types of equipment.

In contrast to the renewable resources, non-renewable resources are the natural resources that can't be remade or upgrade within short period of time. Non-renewable resources are depleted as they are used. Examples of nonrenewable resources include capital and raw materials. That are limited on a total project basis, that is, instead of the limited per-period usage of the renewable resources we have a limited overall consumption of the non-renewable for the entire project. Money, energy and raw material belong to this category. Note that the distinction between renewable and non-renewable resources may be tenuous. In some cases, renewable resources may become non-renewable resources, in others; non-renewable resources may be considered renewable.

III. RELATED WORK

F. F. Boctor [2][3][4] developed three solution strategies for the MRCPSP with renewable resource types only. The first heuristic given in Boctor (1993) is a single-pass approach which employs a parallel scheduling scheme. An activity is in the decision set if all its predecessors are finished and it can be started in at least one of its modes at the current schedule time. Activities are selected from the decision set in the order given by the MSLK (Minimum Slack) priority rule. A chosen activity is scheduled in the mode with shortest duration. In Boctor (1996), all possible activity-mode combinations which can be started at the schedule time are evaluated by applying a lower bound on the increase of the makespan. Finally, Boctor (1997) performs a simulated annealing procedure. SA algorithm is a kind of iterative improvement algorithm in which the initial solution is repeatedly improved by making changes to the current solution until no more change results in a better solution. SA method attempts to avoid local optimum by accepting a current solution that deteriorates the value of the objective function. Statistical experiments were made on two test problem sets of 50 and 100 activities, respectively, generated for the multiple mode case. Results showed the efficiency of the proposed SA algorithm in comparison of previous heuristics evaluated by Boctor. The Boctor's SA algorithm uses an activity list representation in which the position of the activity in the list indicates its priority. To generate a neighbor solution, an activity is chosen at random and its position changed in the list representing the current solution. To assure this new solution is feasible, the chosen activity must be moved to a position in the resulting list that neither precedes any of its predecessors nor succeeds any of its successors. The algorithm then applies the Shortest Feasible Mode (SFM) rule to select the activity mode. This rule determines the mode based on the earliest finish time where there are sufficient resources to perform the considered activity. As this SA algorithm did not consider nonrenewable solutions, initial solutions used by the algorithm was generated with a parallel construction method applying both priority rules MIN SLK and SFM evaluated in Boctor.

Drexl and Grunewald [5] proposed a regret-based biased random sampling approach which jointly employs a serial scheduling scheme and the SPT priority rule. The fact is that the start time of a chosen activity is determined with respect to precedence constraints only. Feasibility with respect to resource constraints is checked solely for the final schedule. The heuristic has been tested extensively on 100 instances with 10 activities, a network complexity of 1.5, three renewable and one nonrenewable resource types as well as different measures of resource scarcity. The best results were obtained with a probability mapping parameter of 2. The sample size - relying on the scarcity of resources - varied between 202 and 3779 in order to generate 100 feasible solutions for each problem, respectively. Depending on the scarcity of resources, an average performance of no more than 3.5% deviation from the optimal objective function value has been documented.

Kolisch, Sprecher, and Drexl [6] have characterized many variations of the resource-constrained project scheduling problem. They defined a set of parameters such as "resource strength" and "network complexity "that characterize the resource-constrainedness and number of precedence relationships in a project plan. *ProGen* is the problem generator they created that uses these parameters to specify the characteristics (and often difficulty) of the problems. In the problem sets described in their paper, Kolisch varied three parameters: complexity, based on the connectivity of the precedence relationship network; resource factor, a measure of the number of resource types; and resource strength, a measure of resource availability. Then they applied their solution method to the problems in order to correlate problem difficulty (based on their algorithm's performance) with the parameters.

Kolisch and Drexl [7] proposed a local search method which first tries to find a feasible solution and second performs a single neighborhood search on the set of feasible mode-assignments. They provided a well-known 0-1 problem formulation and stress the importance of the model by giving applications within production and operations management. By transformation of the knapsack problem showed that the feasibility problem is NP-complete. They proposed a local search method consisting of a construction phase which tries to reach an initial solution, a local search phase which performs a single neighborhood search on the set of feasible mode assignments, and finally, an intensification phase where on the basis of the best mode assignment it is tried to find a schedule with an improved objective function value. An in-depth computational investigation which included a comparison with other heuristics revealed that local search approach is the only heuristic which solves all 10-activity instances and generated the most feasible solutions for the 30-activity instances.

Sprecher and Drexl [8] is proposed branch and bound approach generated a tree by scheduling activities starting with the first task then adding a node to the tree for each task that could be scheduled based upon precedence and resource constraints. Bounds based on partial schedules were used to prune the search tree. The heuristic for expanding the tree used a vector of six measures. Branch and Bound methods cannot solve large problems; the tree is simply too big Although significant progress has been made in the pruning techniques, branch and bound methods are still limited to less than one hundred activities or even fewer in the multi-modal cases, and they still require special heuristics to accommodate variations in resource constraint formulations.

Snoke Hartman [9][10] proposed a new genetic algorithm (GA) approach for solving the MRCPSP. The search space, i.e. the set of the genotypes, consists of the precedence feasible activity sequence and all mode combinations. The phenotype, i.e. schedule, related to a genotype is generated using a serial scheduling scheme. After defining the genetic operators, they extend the procedure by a local search component which systematically improves the solutions found by the GA. The permutation based genetic representation yields better results than a priority rule based encoding. Moreover, the problem specific local search extension is capable of improving the solutions found by the basic GA.

Lin-Yu Tseng and Shih-Chieh Chen [1] proposed the two-phase genetic local search algorithm for solving the MRCPSP. A two phase genetic local search algorithm that combines the genetic algorithm and the local search method to solve this problem. The first phase aims to search globally for promising areas, and the second phase aims to search more thoroughly in these promising areas. A set of elite solutions is collected during the first phase, and this set, which acts as the indication of promising areas, is utilized to construct the initial population of the second phase. By suitable applications of the mutation with a large mutation rate, the restart of the genetic local search algorithm, and the collection of good solutions in the elite set, the strength of intensification and diversification can be properly adapted and the search ability retained in a long term. Most methods that we found in the literature were employed to only conduct short-term experiments; that is, their algorithms were run for just a short time, namely, with 5000 or 6000 schedules to be evaluated. With the short-term experiments, it is difficult to predict the behavior of the algorithms if they were to be run for a long period of time because there is no way of knowing whether the algorithms can still find better solutions with increased running time unless long-term experiments are conducted.

IV. COMPARISON

Author	Year	Method	R/NR	Dataset
Boctor	1993	Heuristic	R	Own
Drexl / Grunewald	1993	Heuristic	RNR	Own
Boctor	1996a	Simulated Annealing	R	Boctor (1993)
Boctor	1996b	Heuristic	R	Boctor (1993)
Kolisch, Drexl	1997	Heuristic	RNR	PSPLIB
Sprecher, Drexl	1998	Branch and Bound	RNR	PSPLIB/Own
Snoke Hartman	2001	Genetic Algorithm	RNR	PSPLIB
Tseng and Chen	2009	Genetic Algorithm	RNR	PSPLIB

V. CONCLUSION

In this paper, we discuss multimode resource constrained project scheduling problem from several aspects such as the activity concept, of the precedence relations and of the resource constraints. The MRCPSP is a difficult problem even in the set of NP-hard problems. Several researchers have proposed different methods to solve this problem. On project scheduling problems with multiple execution modes, the genetic algorithm performed better than deterministic, bounded enumerative search methods, branch and bound, simulated annealing methods. As an effective heuristic method, genetic algorithm is widely used to solve the scheduling problems.

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