Project Scheduling Under Resource Constraints: A Recent Survey

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Abstract:

Due to the fact that project scheduling under resource constraints problem is one of the most intractable problems in Operations Research, it has recently become a popular area for the latest optimization techniques, including virtually all local search paradigms. The sheer diversity and momentum of activity has made developments in project scheduling increasingly difficult to track and assimilate.

This paper provides a high- level bibliography, structured overview and limited critique of nine project scheduling under resource constraints problems; resource-constrained project scheduling problem (RCPSP), preemptive resource-constrained project scheduling problem (PRCPSP), generalized resource-constrained project scheduling problem (GRCPSP) , resource-constrained project scheduling problem with generalized precedence relations (RCPSP-GPR), Time/cost trade-off problems (TCTP) , Discrete time/resource trade-off problems (DTRP), Multi-mode resource-constrained project scheduling problems (MRCPSP), Resource levelling problems (RLP) and Resource-constrained project scheduling with discounted cash flows (RCPSDC). The current developments, strengths, and weaknesses of the scheduling approaches to the stated problems are considered.

1. INTRODUCTION:

According to a research conducted by Standish Group in 2009, only 32% of projects succeeded, meanwhile 44% did not finish within their initial time limit and budget, 24% completely failed (Standish Group, 2009). Therefore, there is a huge demand for better project planning and scheduling practices. Effective project scheduling is critical to the success of a project. The objective of scheduling is to find a way to assign and sequence the use of these shared resources such that project constraints are satisfied and overall costs are minimized.

Interest in new approaches to project scheduling has been stimulated by a variety of pragmatic and theoretical considerations. Among theorists the development of complexity theory and maturation of artificial intelligence have begun to redirect the body of scheduling research. Theoretical advances now appear to have legitimized research on innovative heuristic search procedures which are applied to more realistic scheduling problems. These problems and procedures appear to be more robust than optimization-based scheduling and for this reason hold greater promise for commercial adaptation. Taken as a whole, current market, technological, and theoretical developments have made solutions to both long-standing and newly emerging scheduling problems the subject of intense applied and theoretical research.

Recent advances in the theory and practice of project scheduling cut across traditional disciplinary boundaries. Different research communities have begun to address different aspects of project scheduling under resource constraints problem, bringing to bear a variety of different research traditions, problem perspectives, and analytical techniques. As a consequence, the project scheduling under resource constraints literature has escaped its

ISSN: 2278-0181
Vol. 2 Issue 2, February- 2013

traditional locus in operations research, management science, and industrial engineering. Research on project scheduling recently has been reported in proceedings and journals principally concerned with control theory, artificial intelligence, system simulation, man-machine interaction, large-scale systems and other branches of engineering and computer science. The sheer diversity and momentum of activity has made developments in project scheduling increasingly difficult to track and assimilate.

Project Scheduling under Resource Constraints Problems

Project scheduling under resource constraints problems are characterized by presence of both precedence constraints and resource constraints. Evans and Minieka (1992) stated that the combination of constraints greatly complicates the scheduling problems and gives rise to many non-polynomial (NP) problems. Precedence constraints force an activity not to be started before all its predecessors are finished. Resource constraints arise as follows: in order to be processed, activity j requires k_{jr} units of resource type r $\in$ R during every period of its duration. An overview of Project Scheduling under resource constraints concept is given in fig 1.

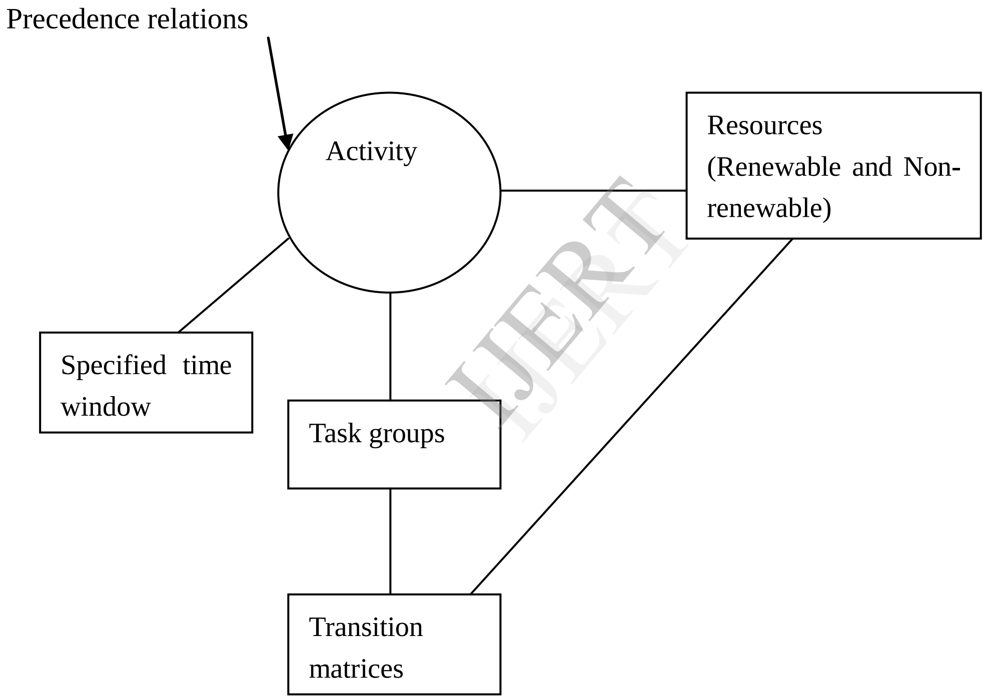

Figure 1: An Overview of Elements of Complex Project Scheduling Problems

It is difficult to find an exact solution for project scheduling under resource constraints problems (Demeulemeester&Herrolean, 2002). The reason for this is that such problems are known to be Non-Polynomial (NP) hard (Leung, 2004; Kolisch& Sprecher, 1996; Demeulemeester&Herrolean, 2002; Kolisch&Hartman, 1999).

Formally, a Project Scheduling under resource constraints problem is defined as the following:

Given: A set of tasks T, a set of resources R, a capacity function C: $R \longrightarrow N$, a duration function D: $T \longrightarrow N$, a utilization function U: $T \times R \longrightarrow N$, a partial order P on T, a deadline d.

Find: An assignment of start times S: $T \longrightarrow N$, satisfying the following:

1. Precedence constraints: if t_1 precedes t_2 in the partial order P,

then $S(t_1) + D(t_1) \leq S(t_2)$

2. Resource constraints: For any time x, let running (x)= {t ∣ $S(t) \leq x < S(t) + D(t)$}. Then for all times x, and all $r \in R$, $\sum_{tt\,t\in run\,running\ \ (xnng\,)} Ut$U(t,r) ≤ C(r).
3. Deadline: For all tasks t: $S(t) \geq 0$ and $S(t) + D(t) < d$.

Table 1 shows a classification of project scheduling under resource constraints problems.

Table 1: Classification of Project Scheduling under Resource Constraints Problems

	RCPSP	PRCPSP	GRCPSP	RCPSP-GPR	DTRTP	MRCPSP	RCPSPDC	RLP	TCTP
Objective	make span	make span	make span	regular	make span	regular	NPV	NPV	NPV
Precedence relations	FS(0)	FS(0)	P	GPR	FS(0)	FS(0)	FS(0)	GPR	GPR
Resources	R	R	R	R	R	R,N,D	R	none	R
Resource availability	constant	variable	variable	variable	constant	variable	Constant	-	variable
Resource requirements	constant	constant	constant	variable	constant	constant	Constant	-	variable
Pre-emption	no	yes	no	no	n	no	No	no	no
Time/resource trade-offs	no	no	no	no	yes	yes	No	no	no
Resource/ resource trade- offs	no	no	no	no	no	yes	No	no	no

Given: FS (0) = finish- start precedence relations with zero time lag.

P = precedence diagramming= SS, SF, FS, FF precedence relations with minimal time lag;

GPR = generalized precedence relations= SS, SF, FS, FF precedence relations with minimal and/or maximal time lag.

R = renewable resource types; N = non-renewable resource types; D = doubly- constrained resource types.

This paper presents an overview that grew out of a desire to assess the breadth and practical implications of contemporary project scheduling under resource constraints research and practice. We have attempted to be comprehensive, although the pace of current activities and the limits of space prohibit guarantees against even significant omissions. Wherever possible, we rely on reference to original research papers and reports and current texts to provide accurate and detailed exposition of the rich sub- structures within the text. The first section introduced project scheduling and project scheduling under resource constraints problems. In the next section we shall state the attributes of a project scheduling environment which constitute the scheduling objectives. Then we shall proceed to classify and explain the project scheduling under resource constraints problem under nine groups while providing the sense and direction of current developments of each project scheduling under resource constraints problem group. Finally, we shall provide concise concluding remarks.

2. QUALITIES OF A PROJECT SCHEDULING DOMAIN

Make span

A complex project schedule must be implemented within a certain duration/ span. For a cyclical project environment, where the same or similar sets of projects are repeated in a regular cycle, this time horizon is specified with project outputs adjusted regularly with respect to changes in the input level. Except for a long-term closure, it is unlikely that a project system actually will be idle at the end of a scheduling horizon. The ability to specify a final system states can be a desirable attribute of a scheduling approach.

Task Size and Costs

Discrete parts of a project are grouped into tasks for implementation. Minimum size of a task are typically established by management decisions based on the project outputs, technologies and resources involved while maximum task sizes are typically governed by performance needs and amount of work to be done. It is required of a scheduling approach to determine task sizes as product scheduling constraints and objectives, represent interruptions in project implementations and account for process- dependent initialization times and costs.

Process Routing

In a classical project scheduling problem, it is expected that tasks are carried out in a strict technological order. However, in reality process routings can be far more complex and even more dynamic. The process routing can vary dynamically given the underlying conditions. Ideally, a scheduling technique would need to be highly flexible with respect to the types of process routings it could capture.

Random Events and Disturbances

In theory, project scheduling formulations, process times, release times and due dates are deterministic (tasks, equipments, manpower and resources are available at all times). In realty, this tends to not be so. A scheduling approach needs to be capable of representing the stochastic scheduling environment. This includes random events and disturbances such as task timing, equipment failures, manpower unavailability, material stock outs, as well as variable job process times, release times and due dates.

Performance Criteria and Multiple Objectives

The classical project scheduling formulation usually specifies a single optimality criterion, such as minimum make span or minimum tardiness. Such criteria tend to implicitly maximize equipment utilization over the (unspecified) scheduling time horizon. Actual project environments clearly embrace multiple, conflicting and sometimes non commensurate constraints and performance objectives. While management typically seeks to minimize costs and maximize the utilization of high- ticket equipments and resources, scheduling objectives also frequently include objectives directed towards minimizing operating stresses. A scheduling technique will be required to capture and balance a great variety of performance criteria.

A given scheduling approach might be classified according to how it represents and deals with these complexities. Since to a greater or lesser degree every project environment is unique, the appropriateness of a given scheduling approach might be assessed by how well its assumptions correlate with the important features of a particular target project environment. It is unlikely that a single scheduling technique can usefully represent all of these complex problem attributes in their full richness. For the most part, each scheduling paradigm considered in the following section addresses only a subset of these attributes.

3. RECENT TREND IN SCHEDULING TECHNIQUES FOR PROJECT SCHEDULING UNDER RESOURCE CONSTRAINTS PROBLEMS

Resource constrained project scheduling problem with generalized precedence relations

This is often denoted as RCPSR- GPR or RCPSP/max extends RCPSP in that it allows start-start, finish- start, start- finish and finish- finish precedence constraints with both minimal and maximal time lags. The RCPSP/max can be formulated as follows:

Minimise $T(S) = s_{n+1}$

Subject to $s_j - s_i \geq \delta_n$ ($(i, j) \in E$) (1)

$$\sum_{i \in V: si \leq t < si+pi} r_{ik} \leq R_k \quad (2)$$

$k = 1 \ldots K,\ 0 \leq t \leq d^*$ (3)

$s_i \geq 0$ ($I \in V$) (4)

$s_0 = 0$ (5)

Where, V = activities= {0, 1,…, n, n+1}; S = schedule= (s_0, s_1, ….s_n.s_{n+1}); K + renewable resource types; Each activity I, requires r_{ik} units of resource k during each period of its duration; d* = maximum project duration.

Exact branch and bound algorithm

(De Reyck and Herroelen 1998) presented a depth- first branch- and – bound algorithm in which nodes in the search tree represent the original project network extended with extra precedence relations to resolve a number of conflicts by using the concept of minimal delaying modes. (Schwindt 1998) provided a branch and bound algorithm that delays activities by adding precedence constraints. (Fest et al. 1999) provided a branch and bound algorithm that dynamically increases the release dates of some activities. (Dorndorf, Pesch, & Phan-Huy 2000) presented a branch and bound algorithm that reduces the search space with a significant amount of resource constraint propagation.

Heuristics

Franck et al (2001) proposed several truncated branch- and – bound techniques, priority – rule methods and schedule – improvement procedures of types tabu search and genetic algorithm and proved that problems could be solved with sufficient accuracy. (Cesta, Oddi, & Smith 2002) presented a heuristic algorithm that begins with all activities scheduled as early as possible and then iteratively finds and levels "resource contention peaks", by imposing additional precedence constraints and restarting. (Cicirello 2003) improves upon priority rule methods by using models of search performance to guide heuristic based iterative sampling.

Ballestin et al(2011) presented an evolution algorithm (EVA) using the conglomerate- based crossover operator, their work being based on Valls et al. (2005). The EVA applies double justification operators (DJmax and DJU) adapted to the specific characteristics of problem to improve all solutions generated in the evolutionary process. Computational results in benchmark sets show it is one of the fastest heuristic algorithms for the problem. Smith and Pyle (2004) presented a new heuristic algorithm that combines the benefits of squeaky wheel optimization with an effective conflict resolution mechanism, called **bulldozing**. Their results shows that the algorithm is competitive with state-of-the-art systematic and non-systematic methods and scales well.

Multi- mode resource- constrained project scheduling problems (MRCPSP)

This problem includes time/ resource and resource/ resource trade- offs, multiple renewable, non-renewable and doubly- constrained resources and a variety of objective functions.

According to Talbot (1982), the MRCPSP can be formulated thus:

Minimize $\sum_{t=esn+1}^{lsn+1} t x_{n+1,1,t}$ (6)

Subject to $\sum_{m+1}^{Mi} \sum_{t=esi}^{lsi} (t + di,m) \leqslant \sum_{m+1}^{Mi} \sum_{t=esi}^{lsi} t x_{j,m,t} \quad \forall (i,j) \in A$ (7)

$\sum_{m+1}^{Mi} \sum_{t=esi}^{lsi} x_{i,m,t} = 1 \quad \forall (i,j) \in A$ (8)

$\sum_{m+1}^{Mi} \sum_{t=esi}^{lsi} r^{y}_{i,m.k} \quad \sum_{s=\max(t-dim,esi)}^{\min(t-1,lsi)} x_{i,m,s} \quad \leq \quad d_k$ (9)

$\forall k \in R^r$ and $t = 1,\ldots,T,$ (10)

$\sum_{i=1}^{n} \sum_{m=1}^{Mi} r^{n}_{i,m.l} \quad \sum_{t=esi}^{lsi} x_{i,m,t} \quad \leq \quad a_l^n \quad \forall l \in R^n$ (11)

$x_{i,m,t} \in \{0,1\} \quad \forall i \in N; m = 1,\ldots,Mi; t = 1,\ldots,T,$ (12)

Where, $x_{i,m,t}$ =1 if acitivity i is performed in mode m and started at time t and 0 otherwise.

Several exact, heuristic and meta-heuristic procedures to solve the MRCPSP have been proposed in the recent years:

Meta- heuristics

Khalizadeh et al (2012) presented a metaheuristic algorithm based on a modified Particle Swarm Optimization (PSO) approach introduced by Tchomte and Gourgand (2009) which uses a modified rule for the displacement of particles for the multi- mode resource constrained project scheduling problem with minimization of total weighted resource tardiness penalty cost (MRCPSP-TWRTPC). This problem involves for each activity, both renewable and non-renewable resource requirements depending on activity mode. A multi- mode particle swarm optimization which combines with genetic operator to solve a bio-objective MRCPSP with positive and negative cash flows was developed by Kazemi and Tavakkoli- Moghaddam (2011). Zhang (2012) proposed an Ant colony optimization (ACO) algorithm with its effectiveness and efficiency justified through a series of computational analyses. Van Peteghem and Vanhoucke (2011) proposed a scatter search algorithm which is among the best performing competitive algorithms in the open literature after they had in 2009 presented artificial immune systems, a new search algorithm inspired by the mechanisms of a vertebrate immune system performed on an initial population set. The AIS algorithm proves its effectiveness by generating competitive results for the different PSPLIB datasets. Ranjbar et al. (2009) proposed a hybridized scatter search procedure to solve the MRCPSP.

A scatter search approach was proposed by Poughaderi et al (2008) to solve this problem and computational experiment performed on a set of instances based on standard test problems constructed by the proGen project generator.

Jarboui et al. (2008) and Zhang et al. (2006) applied the methodology of particle swarm optimization to the MRCPSP to minimize the duration of construction projects.

Heuristics

Ranjbar et al (2012) studied this problem as RCPSP, minimization of total weighted resource tardiness penalty cost (RCPSP- TWRTPC) and developed a meta- heuristic- based GRASP algorithm together with a branch and bound procedure to solve the problem. Coelho and

ISSN: 2278-0181
Vol. 2 Issue 2, February- 2013

Vanhoucke (2011) presented a novel approach to solve MRCPSP by splitting the problem into mode assignment step and a single mode project scheduling step. Their result is comparable to state- of –the art procedures and even outperforms them with run times. A hybrid genetic algorithm was developed by Lova et al (2009) after they had suggested a heuristic algorithm based on priority rules in 2006. Bouleimen and Lecocq (2003) used the simulated annealing approach, Nonobe and Ibaraki (2002) proposed a tabu search procedure. Hartman (2001) proposed a genetic algorithm which outperforms the other heuristics with regard to a lower average deviation from the optimal makespan..Drexl and Grünewald (1993) suggested a regret-based biased random sampling approach. Slowinski et al. (1994) described a single-pass approach, a multi-pass approach, and a simulated annealing algorithm. Kolisch and Drexl (1997) presented a local search procedure. Özdamar (1999) proposed a genetic algorithm based on a priority rule encoding. Bouleimen and Lecocq (1998) suggested a simulated annealing heuristic. Jozefowska et al (2001) proposed simulated annealing approach to MRCPSP.

Exact Procedure

Sprecher and Drexl (1998) developed a branch-and-bound procedure and suggested to use it as a heuristic by imposing a time limit which is, according to the results obtained by Hartmann and Drexl (1998), the currently most powerful algorithm for exactly solving the MRCPSP. The branch and cut method introduced by Heilman (2003) and branch and bound method developed by Zhu et al (2006) are the most powerful exact methods. An exact model was presented by Sabzehparvar and Seyed- Hosseini (2007) for the multi- mode resource-constrained project scheduling problem with generalized precedence relations (MRCPSP-GPR) in which the minimum or maximal time lags between a pair of activities may vary depending on the chosen modes. MRCPSP-GPR is denoted as MPS/temp/C_{max} and is. The proposed model is based on rectangular packing problems and its efficiency was analyzed in the work.

The resource- constrained project scheduling problem

The resource- constrained project scheduling problem (RCPSP) involves scheduling of project activities subject to finish- start precedence constraints with zero time lag and constant renewable resource constraints in order to minimize the project duration. The problem is a generalization of the job shop scheduling problem.

The RCPSP can be conceptually stated as follows:

Min S_{n+1} (13)

Subject to: $S_j \geqslant S_i + p_i \quad \forall \ (i, j) \in E$, (14)

$\sum_{i\in\delta} r_{ik} \leq R_k \quad \forall k \in R \ \forall T \in \{0,\ldots\ldots,T\}$. (15)

$S_i \in \{0,1,\ldots\ldots,T - p_i\} \ \forall I$ (16)

Where δ is the set of activities i that Si ⩽ t ⩽ Si + pi and T is an available upper bound to the optimal project duration (ie makespan of a feasible solution), Si denote the starting time of activity i(with $S_0 = 0$). S_{n+1} = the total project duration or makespan.

A particle swarm optimization (PSO) was proposed by Bakshi et al (2012) for the RCPSP with objective of minimizing cost.

Sadeh et al (2009) presented a liding frame approach which has the advantage of dissecting the original problem to small controllable size sub problems for which exact techniques can be applied and thus neutralizes the complexity of the applied algorithms. Ying et al (2008) introduced a hybrid- directional planning that can make all meta- heuristics more effective in solving RCPSPs. A comprehensive numerical investigation showed that the performance of meta- heuristics significantly increased by using the technique. A hybrid local search technique which resembles the work of Christian et al (2003) was proposed by Igor et al (2007). Debels and Vanhoucke (2006) presented an electromagnetism heuristic based on Birbil and Fang (2003) capable of producing consistently good results for challenging instances of the problem under study. Javier Alcaraz and Concepcion Maroto (2006) presented a hybrid genetic algorithm which uses genetic operators and improvement mechanism and when compared with the best algorithms at the time it was published, performed best. S. Colak et al(2006) presented a hybrid neural approach of the adaptive-learning approach (ALA) which competes favourably with existing scheduling techniques. Debels and Vanhoucke (2005) proposed a genetic algorithm that is bi- population based and one of the best performing heuristics. RCPSPs were solverd by Ahsan and De-bi Tsao (2003) using a bi- criteria heuristic search technique in two phases: pre- processing phase and search phase. They subsequently proposed a weighing technique to increase the algorithm's efficiency. The technique is significant in terms of solution quality and computational performance as their results show. Liess and Michelon (2008) proposed a pure constraint programming approach for the RCPSP based on the idea to substitute resource constraints by a set of sub- constraints generated. The applied the CP approach with a filtering algorithm for the sub- constraints and produced very good results. Demassey (2005) proposed a constant a cooperation method between the integer programming and constraint programming for RCPSP. The originality of their approach is to use some deductions performed by constraint propagation, and particularly by the shaving technique to derive new cutting planes that strengthen the linear programs. Optimal approaches include works by Mingozzi et al (1998) on 0-1 linear programming and Brucker et al(1998) on implicit enumeration with branch and bound.

Discrete time/resource trade-off problems(DTRP)

This problem according to Willy et al (1998) is formulated as follows:

Min Minimize $\sum_{t=en}^{ln} t x_{nlt}$ (17)

Subject to $\sum_{m=1}^{Mi} \sum_{t=ei}^{li} x_{imt} = 1, \; i = 1, 2, \ldots n,$ (18)

$$\sum_{m=1}^{Mi} \sum_{t=ei}^{li} (t+d) x_{i,m.k} \;\leq\; \sum_{m=1}^{Mi} \sum_{t=ej}^{li} t x_{jmi}, \; (i,j) \in H, \quad (19)$$

$$\sum_{i=1}^{n} \sum_{m=1}^{Mi} r_{im} \sum_{s=\max(t-dim,ei)}^{\min(t-1,li)} x_{i,m,t} \;\leq\; a, \; t = 1,2,\ldots,T, \quad (20)$$

$$x_{i,m,t} \in \{0,1\}, \; I = 1, 2, \ldots, n; \; m = 1,2,\ldots M_i; \; t = 0,1\ldots,T, \quad (21)$$

where e_i (l_i) is the critical path based earliest (latest) start time of activity i based on the modes with the smallest duration, T is the upper bound on the project duration, and H is the set of precedence related activities.

The objective function (17) minimizes the makespan of the project. Constraint set (18) ensures that each activity is assigned exactly one mode and exactly one start time. Constraints (19) denote the precedence constraints. Constraints (20) secure that the per period availability of the renewable resource is met. Finally, constraints (21) force the decision variables to assume 0-1 values.

Tabu search procedure which is based on a decomposition of the discrete time/ resource trade-off problem in project networks into a mode assignment phase and RCPS phase with fixed mode assignments was presented by De Ryck et al (1998). They also showed that the search procedure competed well with other local search methods. Fundeling (2006) presented two priority- rule methods. The first based on a serial generation scheme that simultaneously determines the evolution of resource usages and the start time for an activity at a time. The second rile makes use of a parallel generation scheme which schedules parts of the activities in parallel. Erik et al (2000) presented a branch and bouind approach, Tormos and Lova (2001) presented an algorithm which employed a multi- pass technique, Kochetov and Stolyar (2003) proposed an evolutionary algorithm, Bouleiman and Lecocq (2003) proposed a new simulated annealing approach, Akkan et al (2005) presented decomposition- based results for certain benchmarks, Zhang et al (2006) adapted a particle swarm optimization based algorithm, Debles et al (2006) presented a hybrid scatter search- electro magnetism algorithm, Yamashita et al (2006) presented a scatter search algorithm to minimize the resource availability cost. Ranjbar and Kianfar (2007) presented a genetic algorithm, Ranjbar et al (2009) proposed a hybrid scatter search heuristic. Mobini et al (2009) presented an enhanced scatter search algorithm which compares well with existing benchmark algorithms.

Resource levelling problems (RLP)

This is somewhat the dual of the resource- constrained project scheduling problem. The general resource levelling problem may be formulated as follows:

Let $c_k \geq 0$ be a cost for resource k and denoted by $r^s_k(t)$, the resource usage of resource k in period $t \in \{1,\cdots.T\}$ for a given schedule S where $r^s_k(0) = 0$ and the resources are assumed to be unlimited. The objective of the RLP is to minimize some measure of variability (MV) evaluated over the resource usage.

There is also the resource availability cost problem (RACP) which involves individual resource availabilities determining the cost of executing the schedule. Under the assumption of discrete, non- decreasing cost function of the constant availability of the renewable resource types, resource costs are to be determined.

Leon and Balakrishnan (1995) proposed two local search heuristics and a genetic algorithm, which make use of problem-space based neighbourhoods. Kohlmorgen et al. (1996) developed several versions of a parallel genetic algorithm in a multiprocessors system (a system with a total of 16,384 processors). Lee and Kim (1996) developed three metaheuristics, a genetic algorithm, a tabu-search and a simulated annealing algorithm, and compared their performance. The best results are obtained by the simulated annealing algorithm. Hegazy (1999) proposed a gentic algorithm in optimization of resource allocation and levelling.

Özdamar (1999) proposed a hybrid genetic algorithm (for the multi-mode variant of the problem). Hartmann (1998) proposed a genetic algorithm and compared different representations for the solutions. Mori and Tseng (1997) developed a genetic algorithm and compared it with a stochastic scheduling method, thus improving its performance. Alcaraz and Maroto (2001) proposed a genetic algorithm which outperformed existing algorithms. A simulation approach was proposed by Ammar and Yousseif (2002) for resource allocation problem in construction projects. Lombardi and Milano (2012) give a survey of optimal solutions including constraint programming, operations research and hybrid algorithms for resource allocation problems and provide an overview of the state- of – art models, propagation/ bounding techniques and search strategies. Kumanan et al (2004) proposed the use of a heuristic and a genetic algorithm for scheduling a multi- project environment with an objective to minimize the makespan of the projects which when validated proved competent. An extended resource levelling model was introduced by Roca et al (2008) which abstract real life projects that consider specific work ranges for each resource. They formulated the model as a multiobjective optimization problem and proposed a multiobjective genetic algorithm- based solver to optimize it and also proposed an intelligent encoding for the solver. Their poposed solver reported competitive and performing results. A tree- based enumeration approach was proposed by Gather and Zimmermann(2009) for RLP. Hu and Flood (2012) presented an integrated scheduling method to minimize the project duration and resource fluctuation by using the strength Pareto evolutionary approach 11 (SPEA 11) and also proposed an innovative representation scheme for SPEA 11. Their results showed that the method yields better results than other methods.

Resource-constrained project scheduling with discounted cash flows (RCPSP-DC)

This problem involves the scheduling of project activities to maximize the net present value of the project in the absence of resource constraints. The project is represented by an activity-on-the-node (AoN) network G = (N, A), where the set of nodes, N, represents activities, and the set of arcs, A, represents finish-start precedence constraints with a time lag of zero.

Generally the problem is formulated thus:

Maximize $\sum_{i=2}^{n-1} cie^{-\alpha fi}$ (22)

Subject to:

$f_i \leq f_i - d_j \lor (i,j) \in A$ (23)

$f_n \leq \delta_n$ (24)

$f_1 = 0$ (25)

Where α= discount rate; c_i = terminal value of cash flows of activity i at its completion; deadline = δn; d_i (1 < i < n) = duration of an activity. If a non- negative integer variable f_i (1≤ I ≤ n) denotes the completion time of activity i, its discounted value at the beginning of the project is $cie^{-\alpha fi}$.

Kamburowski (1990) presented an exact solution procedure for the problem based on the approach by Grinold (1972). Demeulemeester et al (1996) proposed an activity-oriented recursive search algorithm for the max-npv problem, Vanhoucke et al (2001) updated the recursive search algorithm and incorporated it in a branch-and-bound algorithm. The recursive search algorithm exploits the idea that positive cash flows should be scheduled as early as possible while negative cash flows should be scheduled as late as possible within the precedence constraints. The procedure has been coded and validated on two problem sets. De Reyck and Herroelen (1996) extended the procedure using the so-called distance matrix D in order to cope with generalized precedence relations. De Reyck and Herrolelen (1998) embedded the procedure of De Reyck and Herroelen (1996) into a branch-and-bound algorithm. Neumann and Zimmermann (2000) adapted the procedure by Grinold (1972) and investigated different pivot rules. Schwindt and Zimmermann (2001a) and (2001b) presented a steepest ascent algorithm and compared different solution procedures on two randomly generated test sets. Ulusoy (2001) solved a set of 93 problems from literature under four different payment models and resource type combinations with the GA approach employed in satisfactory computation times. The GA outperformed a domain specific heuristic. Mika et al (2005) solved a multi-mode version of this problem by proposing a simulated annealing plus tabu search procedure. Test problems are constructed b y ProGen project generatorand the meta heuristics are computational compared. Vanhoucke (2006) presented a hybrid recursive search procedure for this problem and in 2010 presented a scatter search algorithm I which he assumed fixed payments associated with the execution of project activites and developed a heuristic optimization procedure to maximize the net present value of the project subject to the precedence and renewable resource constraints. Chen and Chyu (2010) developed a hybrid of branch and bound procedure and memetic algorithm which performs well for all instances of different problem sizes. A meta- heuristic scatter approach was developed by Khalizadeh et al (2011) for solving the resource- constrained project scheduling problem with discounted cash flows of weighted earliness- tardiness penalty costs (RCPSP-DCWET) while considering the time value of money. Their results show the efficiency of the propose meta-heuristic procedure. Vanhoucke (2009) presented a genetic algorithm to solve the single mode of this problem by considering a problem formulation where the pre- specified project deadline is not set as a hard constraint, but rather as a soft constraint that can be violated against a certain penalty cost. Icmeli and Erenguc (19696),Padman and Smith- Daniels (1993), Padman et al (1997), Russell (1986), Smith- Daniels and Aquilano (1987) and Smith- Daniels et al (1996) are some of the works in this area.

The preemptive resource-constrained project scheduling problem (PRCPSP)

This problem is an extension of RCPSP in that it allows for activity pre-emption at integer points in time. The PRCPSP can be formulated thus:

Minimize $f_{n,0}$ (26)

Subject to

$f_i d_i \leqslant f_{j,0}$ for all $(i, j) \in H$ (27)

$f_{i,j-1} + 1 = 0$ (28)

$f_{1,0} = 0$ (29)

$\sum_{i \in Si} r_{ik} \leq a_k$ $k = 1, \ldots, K; t = 1, \ldots, f_{n,0}$ (30)

Where, $f_{1,0} =$ the earliest time that an activity i can be started = the latest finish time of all predecessors of activity I since only finish- start relations with lag of zero are allowed; d_i = duration of activity i.

The literature on solution methods for the preemptive resource constrained project scheduling problem is quite scarce. Kaplan (Kaplan, 1988) was the first to study the problem (PRCPSP) by formulating it as a dynamic program and solving it using a reaching procedure. Demeulemeester and Herroelen (1996) developed a branch and bound algorithm for the problem. S. Verma (2006) presented a best- first tree search method. Damay et al (2007) presented a linear programming based algorithm, Nadjafi and Shadrok (2008) proposed a pure integer formulation based solution method. Their objective was to schedule the activities of the project scheduling problem in order to minimize the total cost of earliness- tardiness and pre-emption penalties subject to the precedence constraints, resource constraints and a fixed deadline on project. Ballestin et al (2008) & Vanhoucke and Debels (2008) proposed heuristics for the problem. V.V.Peteghem and Vanhoucke (2010) presented a genetic algorithm for pre-emptive and non- pre-emptive multi- mode resource constrained project scheduling problem.

The Generalized Resource- Constrained Project Scheduling Problem

This also is an extension of RCPSP to the case of minimal time lags, activity release dates and deadlines and variable resource availabilities.

Maximize f (T) (31)

Subject to $T_{i(k)} + d_{i(k)} \leq T_{j(k)}$, $k = 1,\ldots,.K$ (32)

(other known feasibility constraints) (33)

Where T_i is the start time decision variable for the activity i. The I activity decision variables thus compose the vector T. the parameter d_i represents the duration of activity i, i(k) is the predecessor actity of the kth precedence constraint and i (k) is the successor of that constraint.

Kuster et al (2010) proposed a Local Rescheduling as a generic approach to partial rescheduling and their results show that LRS outperforms previous approaches. A specific evolutionary algorithm was presented by Kuster et al (2009) which identifies good quality solutions to relatively large- sized problems gives fast convergence on good or optimal schedules. Kuster and Jannach (2006) presented an evolutionary approach for solving a generalized resource- constrained project scheduling problem which was applied in disruption management. A version of heuristic which takes into account the due date of a project was constructed by Ballestin et al (2006). They also presented an instance generator that generates due dates for computational study and adapted the technique for justification to deal with due dates and deadlines and to show its profitability. Sampson et al (2006) proposed local search techniques which has advantages of handling arbitrary objective functions and constraints and its effectiveness over a wide range of problem sizes. Their techniques indicate a significant improvement over the best heuristic results reported to date for this problem.

Zhu et al. (2005) focused on the identification of an optimal solution for classical forms of modification (eg. durations and resource assignments), Artigues et al (2003)concerned with the dynamic insertion of activities, where each occurrence of an unexpected activity corresponds to a disruption, Elkhyari et al (2004) provided possibilities to handle over-constrained networks based on the excessive use of so- called explanations, Beck et al proposed an approach in which a Probability of Existence (PEX) can be defined for any activity.

Time/ cost trade- off problem

This involves the duration of project activities being a discrete, non-increasing function of the amount of a single non- renewable resource committed to them. Three objectives are classified as the deadline problem aiming at minimizing the total cost of the project while meeting a given deadline (find Φ* subject to $c_{\Phi*} = \min_{\Phi\in\alpha}\{ c_\Phi / t_\Phi \leq$ project deadline$\}$, budget problem aiming at minimizing the project duration without exceeding a given budget (find Φ* subject to $t_{\Phi*} = \min_{\Phi\in\alpha}\{ t_\Phi / c_\Phi \leq$ budget$\}$and a third objective aiming at minimizing the project duration without exceeding a given budget (when the objective is to identify the entire Time-Cost Problem profile for the project network, the problem is to find:

$B = \{\Phi^* \in \alpha /$ thee does exist another $\Phi \in \alpha$ with $(t_\Phi \leq t_{\Phi*}) \wedge (c_\Phi \leq c_{\Phi*})\}$.

Where Φ = instance, c_{ij} = cost involved, t_{ij} = time involved.

Vanhoucke and diebel (2007) in their work studied the three extensions to the time/ cost trade off problem namely time- switch constraints, work continuity constraints and NPV maximization and subsequently developed a meta heuristic to provide near- optimal solutions for the problems. Srivastava et al (2010) proposed a hybrid meta heuristic (HMH) combining a genetic algorithm with simulated annealing to solve discrete version of the multiobjective time- cost trade off problem. They employed the HMH to solve two cases of the problem.

Demeuslemeester et al (1996) presented two procedures and programmed them in C and also tested them on large set of representative networks to give a good indication of their performance, and indicate the circumstanc3es in which either procedure perform best. The first procedure is for finding the minimal number of reductions necessary to transform a general network to a seriest- parallel network while the second is for minimizing the estimated number of possibilities that need to be considered during the solution procedure. A network decomposition/ reduction was presented by De at al (1995) for this problem and analyzing its difficulty. They inferred that the popular project management software packages do not include provisions for the time- cost trade- off analyses. Richard et al (1995) had developed a nonlinear time – cost trade off model with quadratic cost relations, Vanhoucke (2005) applied a branch and bound method to solve discrete TCT problem with time switch constraints.

4. CONCLUSION

This paper has summarized an extensive array of research on the various aspects of the project scheduling under resource constraints problems. The importance of project scheduling under resource constraints problems will in future increase as the limitation on resources will be tighter, hence we expect to see more good portion of the project scheduling literature developing around the various project scheduling under resource constraints problems

REFERENCES

1. Ahsan M.K., Tsao D., Solving resource-constrained project scheduling problems with bi-criteria heuristic search techniques, journal of system science and systems engineering 2003; 12(2): 190-203, DOI:10.1007/s11518-006-0129-3.

2. Akkan C, Drexl A, Kimms A., Network decomposition-based benchmark results for the discrete time-cost tradeoff problem 2005; European Journal of Operational Research 165: 339–358.

3. Alcaraz J., Maroto . C., A robust genetic algorithm for resource allocation in project scheduling, annals of operations research 2001; 102(1-4): 83- 109, DOI:10.1023/a:1010949931021.

4. Ammar M.A., Mohieldin Y.A., Resource constrained project scheduling using simulation ; Const Manag & Econs 2002; 20: 323- 330.

5. Artigues C., Michelon P., Reusser S., Insertion techniques for static and dynamic resource constrained project scheduling, European Journal of OR 2003; 149.

6. Bakshi T., Sarka B, Sanyal S.K., An evolutionary algorithm for multi- criteria resource constrained project scheduling problem based on PSO, ICCCS 2012; Procedia Tech 6:pp.231-238.

7. Ballestin F., Valls V., Quintanilla S., Due dates and RCPSP, Perspective in modern project scheduling, international series in operations research & management science 2006;92(1): 79-104, DOI:10.1007/978-0-387-33768-5_4.

8.Ballestin F, Valls V., Quintanilla S., Pre-emption in resource- constrained project scheduling, European journal of operational research 2008; 189: pp.1136-1152.

9. Beck J.C., Fox M.S., Constraint Directed Techniques for Scheduling with Alternative Activities, Artificial Intelligence 2000;121: 211–250

10. Birbil S.I., Fang S.C., An electromagnetism-like mechanism for global optimization,

Journal of Global Optimization 2003;25: 263-282.

11. Bouleimen, K., Lecocq, H., A new efficient simulated annealing algorithm for the resource-constrained project scheduling problem and its multiple mode version. Eur. J. Oper. Res. 2003; 149: 268–281.

12. Bouleimen K., Lecocq H., A new efficient simulated annealing algorithm for the resource-constrained project scheduling problem, in: Proceedings of the Sixth International Workshop on Project Management and Scheduling 1998; (eds. G. Barbarosoˇ glu, S. Karabatı, L. Özdamar and G. Ulusoy (Boˇ gaziçi University Printing Office, Istanbul): 19–22.

13. Brucker P., Knust S., Schoo A., Thiele O., A branch and bound algorithm for the resource-constrained project scheduling problem. European Journal of Operational Research 1998; 107(2): 272–288.

14. Cesta A.; Oddi A., Smith S.. A constraint- based method for project scheduling with time windows. Journal of Heuristics 2002; 8(1):109–136.

15. Chen A.H.L, Chyu C., Economic optimization of resource- constrained project scheduling:a two- phase metaheuristic approach, journal of Zhejiang university-science 2010; 11(6):481-494,DOI:10.1631/jzuz.C0910633.

16. Christian A., Michelon P., Reusser S., Insertion techniques for static and dynamic resource-constrained project scheduling. European Journal of Operational Research 2003;149: 249–267.

17. Cicirello V. A., Boosting Stochastic Problem Solvers Through Online Self-Analysis of Performance. Ph.D. Dissertation, The Robotics Institute, Carnegie Mellon Univ. 2003.

18. Coelho J., Vanhoucke M., Multi- mode resource- constrained project scheduling using RCPSP and SAT solvers, Eur J of Oper Res 2011, 213(1) :73-82.

19. De P., Dunne E.J, Ghosh Jay B., Wells Charles E ., The discrete time- cost trade- off problem revisited, Eur J of Oper Res 1995, 81:225-238.

20. Damay J., Quilliot A., Sanlaville E., Linear programming based algorithms for preemptive and non-preemptive RCPSP, European Journal of Operational Research 2007; 182:1012–-1022

21. Debels D. ,Vanhoucke M., A bi- population based genetic algorithm for the resource-constrained project scheduling problem, computational science and its applications-ICCSA 2005, LNCS,(3483/2005):85-117,DOI:10.1007//11424925_41.

22. Debels D.,Vanhoucke M., The electromagnetism meta- heuristic applied to the resource-constrained project scheduling problem, artificial evolution 2006;LNCS,(3871/2006): 259-270,DOI:10.1007/11740698_23.

23. Debles D, Reyck BD, Leus R, Vanhoucke M., A hybrid scatter search/electromagnetism meta-heuristic for project scheduling.Eur J Oper Res 2006;169:638–653

24. Demassey S, Artigues C Michelon P, Constraint-propagation- based cutting planes: an application to the resource- constrained project scheduling problem, INFORMS J on Comp 2005; 17(1):52- 65.

25. De Reyck B., Herroelen W., A branch-and-bound procedure for the resource-constrained project scheduling problem with generalized precedence constraints,European Operational Research 1998; 111: 152–174. DOI:10.1016/S0377-2217(97)00305-6.

26. De Reyck B, Demeulemeester E, Herroelen W., Local search methods for the discrete time/ resource trade- off problem in project networks, Naval research logistics

1998;45:553-578.

27. Dorndorf U., Pesch E., Phan-Huy T. , A time-oriented branch-and-bound algorithm for resource-constrained project scheduling with generalised precedence constraints. Manag. Sci. 2000, 46(10):1365–1384.

28. Drexl A., Grünewald J., Nonpreemptive multi-mode resource-constrained project scheduling, IIE Transactions 1993;25: 74–81.

29. Demeulemeester E, Herroelen W, An efficient optimal solution procedure for the preemptive resource constrained project scheduling problem, European Journal of the Operational Research 1996;90: 334-348.

30. Demeulemeester E, Herroelen W, Project Scheduling: A Research Handbook, , Kluwer Academic Publishers, Norwell MA 2002: 203.

31. Demeulemeester E., Herroelen W., Van Dommelen P., An optimal recursive search procedure for the deterministic unconstrained max-npv project scheduling problem 1996; Research Report 9603, Department of Applied Economics, Katholieke Universiteit Leuven, Belgium.

32. Demeulemeester E, Herroelen W., Elmaghrab S.E., Optimal procedures for the discrete time/ cost trade- off problem in project networks, Eur J of Oper Res 1996; 88: 50-68.

33. Demeulemeester E, De Reyck B, Herroelen W, The discrete time/ resource trade- off problem in project networks: a branch and bound approach, IIE Transactions 2000;32(11): 1059-1069, DOI: 10.1023/A:1013785108131.

34. De Reyck B., Herroelen W., An optimal procedure for the unconstrained max-npv project scheduling problem with generalized precedence relations 1996; Research Report 9642, Department of Applied Economics, Katholieke Universiteit Leuven, Belgium.

35. De Reyck B., Herroelen W., An optimal procedure for the resource-constrained project scheduling problem with discounted cash flows and generalized precedence relations, Computers and Operations Research 1998; 25: 1-17.

36. Elkhyari, A., Guéret, C., Jussien, N., Constraint Programming for Dynamic Scheduling Problems, In: ISS'04 Int. Scheduling Symposium 2004: 84–89

37. Evans R., Minieka E, Optimization Algorithms for Networks and Graphs, Marcel Dekker Inc. New York 1992: 39.

38. Fest A.; Möhring R. H., Stork F., Uetz M., Resource constrained project scheduling with time windows: A branching scheme based on dynamic release dates 1999; Technical Report 596, TU Berlin, Germany.

39. Franck B., Neumann K., Schwindt C, Trunccated branch and bound, schedule construction, and schedule improvement procedures for resource constrained project scheduling, In OR Specktrum 2001; 23:297–324.

40. Fundeling C., Priority-Rule methods for project scheduling with work content constraints, operations research proceedings 2006,2006,(XVIII):529-534,DOI:10.1007/978-3-540-69995-8_84.

41. Gather T., Zimmermann J., Exact methods for the resource levelling problem, Multidisciplinary Int Conf on Sched: Theory and Applications 2009, MISTA

42. Grinold, R.C., The payment scheduling problem, Naval Research Logistics Quarterly 1972; 19:123-136.

43. Hartmann S., A competitive genetic algorithm for resource-constrained project scheduling,

Naval Research Logistics 1998; 45: 733–750.
44. Hartmann S., Project Scheduling with Multiple Modes: A Genetic Algorithm, Annals of Operations Research 2001; 102: 111–135.
45. Hartmann S., Drexl A., Project scheduling with multiple modes: A comparison of exact algorithms, Networks 1998;32: 283–297.
46. Heilmann R., A branch and bound procedure for the multi- mode resource constrained project scheduling problem with minimum and maximum time lags, European J of Oper Research 2003;144(2):348 – 365.
47. Hegazy T., Optimization of resource allocation and levelling using genetic algorithm, J Constr Eng Manage 1999; 125:167-175.
48. Hu J.,,Flood I., A multi- objective scheduling model for solving the resource- constrained project scheduling and resource levelling problems, Computing in Civil Engr. 2012, http://ascelibrary.org/doi/pdf/10.1061/9780784412343.0007
49. Icmel O, Erenguc S.S, A tabu search adaptation to resource constrained project scheduling problem with discounted cash flows, Com and Oper Res 1996;21:841-854.
50. Jarboui B., Damak N., Siarry P., Rebai A., A combinatorial particle swarm optimization for solving multi-mode resource-constrained project scheduling problems. Appl. Math. Comput. 2008; 195: 299–308
51. Javier A. , Maroto C, A hybrid genetic algorithm based on intelligent encoding for project scheduling, international series in operations research & management science 2006; 92(11): 249- 274, DOI: 10.1007/978-0-387-33768-5_10.
52. Jozefowska J, Mika M, Rozycki R, Waligora G, Weglarz J, Simulated annealing for multi-mode resource- constrained project scheduling, annals of operations research 2001;102(1-4):137-155,DOI:10.1023/A:10110954031930.
53. Kaplan L.A., Resource constrained project scheduling with preemption of jobs, Unpublished Ph.D Thesis 1988, University of Michigan.
54. Kazemi F.S, Tavakkoli- Moghaddam R, Solving a multi- mode resource constrained project scheduling problem with particle swarm optimization, Int J of Acad Res 2011; 3(1):103-110.
55. Khalilzadeh M, Kianfar F, Ranjbar M, A scatter search algorithm for RCPSP with discounted weighted earliness- tardiness costs, Life Sci Journal 2011; 8(2): 634-640.
56. Khalilzadeh M, Kianfar F, Chaleshtari A.S, Shadrokh S, Ranjbar M, A modified PSO A lgorithm for minimizing the total costs of resources in MRCPSP, mathematical problems in engr. 2012; DOI:10.1155/2012/365697.
57. Kochetov Y, Stolyar A, Evolutionary local search with variable neighbourhood for the resource constrained project scheduling problem. In: Proceedings of the 3rd international workshop of computer science and information technologies 2003, Russia.
58. Kohlmorgen U, Schmeck H, Haase K, Experiences with fine-grained parallel genetic algorithms, Working paper, Institut für Angewandte Informatik und Formale Beschreibungsverfahren, Universität Karlsruhe, Karlsruhe 1996, Germany.
59. Kolisch R, Drexl A, Local search for nonpreemptive multi-mode resource-constrained project scheduling, IIE Transactions 1997;29: 987–999.
60. Kolisch R, Hartman S, Heuristic algorithms for solving the resource constrained project scheduling problem: classification and computational analysis," Chapter 7 in 61. Weglarz J.

(Ed.) Handbook of recent advances in Project scheduling, Kluwer academic publishers 1999;147-178.

62. Kolisch R, Sprecher A, "PSPLIB - A Project Scheduling Problem Library". European Journal of Operational Research 1996: 205-216.

63. Kumanam S, Jegan Jose G, Raja K, Multi- project scheduling using an heuristic and a genetic algorithm, Int J Adv Manuf Technol 2006;31:360-366, DOI 10.1007/s00170-005-0199-2.

64. Kuster J, Jannach D, Handling airport ground processes based on resource- constrained project scheduling, advances in applied artificial intelligence 2006; LNCS,4031/2006:166-176,DOI:10.1007/11779568_20.

65. Kuster J, Jannach D, Friedrich G, Extending the RCPSP for modelling and solving disruption management problems, applied intelligence 2009;31(3):234-253,DOI:10.1007/s10489-008-0119-x.

66. Lee K, Kim Y.D, Search heuristics for resource constrained project scheduling, Journal of the Operational Research Society 1996; 47: 678–689.

67. Leon V.J. Balakrishnan R, Strength and adaptability of problem-space based neighborhoods for resource-constrained scheduling, OR Spektrum 1995;17: 173–182.

68. Leung J.Y.T, Handbook of scheduling, CRC press/Chapman & Hall 2004;.

69. Lombardi M, Milano, Optimal methods for resource allocation and scheduling: a cross-disciplinary survey, Con 2012; 17:51-85, DOI: 10.1007/s10601-011-9115-6.

70. Liess O, Michelon P, A constraint programming approach for the resource- constrained project scheduling problem, Annals of Oper Res 2008;157(1):25-36, DOI:10.1007/s10479-007-0188-y.

71. Lova A, Tormos P, Barber F, Multi- mode resource constrained project scheduling: scheduling schemes, priority rules and mode selection rules, Inteligencia Artificial 2006;10(30):69-86.

72. Lova A, Tormos P, Caervantes M, Barber F, An efficient hybrid genetic algorithm for scheduling projects with resource constraints and multiple execution modes, International J of Prod Eco 2009;117(2):302- 316.

73. Madhdi Mobini M.D., Rabbani M, Amalnik M.S, Razmi J, Rahimi- Vahed A.R, Using an enhanced scatter search algorithm for resource- constrained project problem, soft computing- a fusion of foundations, methodologies and applications 2009; 13(6): 597- 610, DOI: 10.1007/s00500-008-0337-5.

74. Mika M, Waligora G, Weglarz J, Simulated annealing and tabu search for multi- mode resource constrained project scheduling with positive discounted cash flows and different payment models, Eur J of Oper Res 2005;164(3):639-668.

75. Mingozzi A., Maniezzo V., Ricciardelli S., Bianco L., An exact algorithm for the resource-constrained project scheduling problem based on a new mathematical Formulation, Management Science 1998;44(5):714–729.

76. Möhring R.H., Schulz A.S., Stork F., Uetz M., On project scheduling with irregular starting time costs, Operations Research Letters 2001; 28: 149-154 .

77. Mori M, Tseng C.C., A genetic algorithm for multi-mode resource constrained project scheduling problem, European Journal of Operational Research 1997;100: 134–141.

78. Nadjafi B.A., Shadrokh S, The preemptive resource- constrained project scheduling

problem subject to due dates and pre-emption penalties: an integer programming approach, journal of industrial engineering 2008;1:35-39.
79. Neumann K., Zimmermann J., Exact and heuristic procedures for net present value and resource levelling problems in project scheduling, European Journal of Operational Research 2000; 127: 425-443.
80. Özdamar L, A genetic algorithm approach to a general category project scheduling problem, IEEE Transactions on Systems, Man, and Cybernetics, Part C: Applications and Reviews 1999; 29: 44–59.
81. Padman R, Smith- Daniels R.E, Smith- Daniels V.L, Early- tardy cost trade- offs in resource constrained projects with cash flows: An optimization- guided heuristic approach, Eur J Ope Res 1993; 64:295-311.
82. Padman R, Smith- Daniels D.E, Smith- Daniels V.L, Heuristic scheduling of resource-constrained projects with cash flows, Naval Res Logistics 1997;44:365-381.
83. Peteghem V.V, Vanhoucke M, An artificial immune system for the multi- mode resource-constrained project scheduling problem 2009;
84. Peteghem V.V, Vanhoucke M, A genetic algorithm for the preemptive and non- preemptive multi- mode resource- constrained project scheduling problem, european journal of operational research 2010; 201(2):409-418.
85. Peteghem V.V., Vanhoucke M, Using resource scarceness characteristics to solve the multi-mode resource-constrained project scheduling problem, J Heuristics 2011; 17:705–728, DOI 10.1007/s10732-010-9152-0.
86. Pesek I, Schaerf A, Zerovnik J., Hybrid local search techniques for the resource-constrained project scheduling problem, hybrid metaheuristics, lecture notes in computer science 2007; 4771/2007: 57- 68, DOI: 10.1007/978-3-540-75514-2_5.
87. Pourghaderi A.R, Torabi S.A, Talebi J, Scatter search for multi- mode resource constrained project scheduling problems, IEEE 2008;978-1-4244-2630-0/08
88. Ranjbar M., Kianfar F, Solving the discrete time/resource trade-off problem in project scheduling with genetic algorithms, Applied Mathematics and Computation 2007; 191: 451–456.
89. Ranjbar M., De Reyck B., Kianfar F.: A hybrid scatter-search for the discrete time/resource trade-off problem in project scheduling. Eur. J. Oper. Res 2009; 193:35–48.
90. Ranjbar M, Khaliladeh M, Kianfar F, Etminani K, An optimal procedure for minimizing total weighted resource tardiness penalty costs in the resource- constrained project scheduling problem, Computers and Industrial Engineering 2012; 62(1): 264-270,
91. Richard F.D., Hebert J.E., Verdini W.A., Grimsrud P.H., Venkateshwar, Nonlinear time/ cost trade- off models in project management, Comp & Ind Engr 1995;(28): 219- 229.
92. Roca J, Pugnaghi E, Libert G, Solving an extended resource levelling problem with multiobjective evolutionary algorithms, WASET 2008;48.
93. Russell R.A, A comparison of heuristics for scheduling projects with cash flows and resource restrictions, Mgt Sci 1986; 32:1291-1300.
94. Sadeh A, Cohen Y, Zwikael O, Using sliding frame approach for scheduling large and complex projects, IEEE IEEM 2009; 978-1-444-4870-8/09.
95. Sabzehparvar M., Seyed-Hosseini S.M, A mathematical model for the multi-mode resource- constrained project scheduling problem with mode dependent time lags, J

Supercomput 2008; 44: 257-273, DOI:10.1007/s11227-007-0158-9.
96. Scott E. Sampson, Elliot N. Weiss, Local search techniques for the generalized resource constrained project scheduling problem, NRL 1993;40(5): 665-675.
97. Schwindt, C., A branch-and-bound algorithm formthe resource-constrained project duration problem subject to temporal constraints. Technical Report WIOR-544, Universitat Karlsruhe, Germany 1998;
98. Schwindt C., Zimmermann J., Maximizing the net present value of projects subject to temporal constraints, WIOR-Report-536, Institut für Wirtschaftstheorie und Operations Research, University of Karlsruhe, Germany 1998.
99. Schwindt C., Zimmermann J., A steepest ascent approach to maximizing the net present value of projects, Mathematical Methods of Operations Research 2001; 53:435-450.
100. Selcuk C., Anurag A.l, Selcuk S. E, Resource Constrained Project Scheduling: a Hybrid Neural Approach, perspectives in modern project scheduling, international series in operations research & management science 2006;92(11):297- 318, DOI: 10.1007/978-0-387-33768-5_12.
101. Slowinski R, Soniewicki B, eglarz J.W, DSS for multiobjective project scheduling subject to multiple-category resource constraints, European Journal of Operational Research 1994;79: 220–229.
102. Smith- Daniels D.E., Aquilano N.J., Using a late- start resource- constrained project schedule to improve project net present value, Decision Sci 1987; 18: 617-630.
103. Sprecher A, Drexl A, Multi-mode resource-constrained project scheduling by a simple, general and powerful sequencing algorithm, European Journal of Operational Research 1998;107: 431–450.
104. Standish group, CHAOS Summary 2009; Report online available at: http://www1.standishgroup.com/newsroom/chaos_2009.php.
105. Srivastava S, Pathak B, Srivastrava K, Project Scheduling: time- cost tradeoff problems, Comp Intelli. in Optimization 2010; ALO 7:325-357.
106. Talbot F, Resource- constrained project scheduling problem with time- resource trade-offfs: The nonpreemptive case, Mgt Sci 1982;28:1197 – 1210.
107. Tchomte S.K., Gourgand M, Particle swarm optimization: a study of particle displacement for solving continous and combinatorial optimization problems, Int J of Prd Econ 2009;121(1): 57-67.
108. Tristan B. S, John M. P, An Effective Algorithm For Project Scheduling With Arbitrary Temporal Constraints, American Association for Artificial Intelligence 2004; (www.aaai.org).
109. Tormos P, Lova A, A competitive heuristic solution technique for resource-constrained project scheduling.Ann Oper Res 2001;102:65–81
110. Ulusoy G, Sivrikaya-Serifoglu F, Sahin S, Four payment models fo the multi-mode resource constrained project scheduling problem with discounted cash flows, annals of Oper Res 2001;102:237-261.
111. Valls V, Ballestin F, Barrios A, An Evolutionary Algorithm for the Resource- Constrained Project Scheduling Problem with Minimum and Maximum Time Lags, Journal of Scheduling 2011; 14(4): 391- 406, DOI: 10. 1007/s10951- 009- 0125- 9.
112. Valls V., Ballestín F., Quintanilla S., Justification and RCPSP: a technique that pays. European Journal of Operational Research 2005; 165: 375–386.

doi:10.1016/j.ejor.2004.04.008.

113. Vanhoucke M, New computational results for the discrete/cost trade- off problem with time- switch constraints, Eur J of Oper Res 2005;165: 359- 374.

114. Vanhoucke M, An efficient hybrid search algorithm for various optimization problems, evolutional computation in combinatorial optimization, lecture notes in computer science 2006 ;(3906/2006):272- 283, DOI: 10.1007/11730095_23.

115. Vanhoucke M, A genetic algorithm for the net present value maximization for resource constrained projects, EVOComp 2009; LNCS 5482:13-24.

116. Vanhoucke M, Debels D, The discrete time/ cost trade- off problem: extensions and heuristic procedures, J Sched 2007;10:311-226, DOI 10:1007/s10951-007-0031-y.

117. Vanhoucke M, Debels D, The impact of various activity assumptions on the lead time and resource utilization of resource- constrained projects, computers and industrial engineering 2008;54:140-154.

118. Vanhoucke M., Demeulemeester E., Herroelen W., On maximizing the net present value of a project under renewable resource constraints, Management Science 2001; 47:1113-1121.

119. Verma S, Exact methods for the preemptive resource- constrained project scheduling problem, research and publication, Indian institute of management 2006, ahmedabad, india, w.p.no.2006-03-08.
http://www.iimahd.ernet.in/assets/snippets/workingpaperpdf/2006-03-08sverma.pdf.

120. Yamashita DS, Armentano VA, Laguna M, Scatter search for project scheduling with resource availability cost. Eur J Oper Res 2006;169:623–637

121. Ying K.C, Lin S.W., Lee Z.J., Hybrid- directional planning: improving improvement heuristics for scheduling resource- constrained projects, Int J Adv ManufTechnology 2007;41:358–366DOI:10.1007/s00170-008-1486-5.

122. Zhang,H, Ant colony optimization for multi- mode resource- constrained project scheduling, J Manage. Eng 2012;28(2):150-159, DOI:10.1061/(ASME)ME.1943-5479.0000089.

123.Zhang,H.,Tam,C.,Li,H.,Multi-modeprojectschedulingbasedonparticleswarmoptimization. Comput.-Aided Civ. Infrastruct. Eng. 2006;21; 93–103.

124. Zhang H, Li H, Tam CM, Particle swarm optimization for resource-constrained project scheduling. Int J Project Manage 2006; 24:83–92.

125. Zhu G., Bard J.F., Yu G., Disruption management for resource-constrained project scheduling, Journal of the Operational Research Society 2005; 56: 365–381.

126. Zhu G., Tam C.M., Li H., Multimode project scheduling based on particle swarm optimization, Computer- Aided Civil and Infrastructure Engineering 2006; 21(2):93- 103.