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Particle swarm optimization for resource Constrained-project scheduling problem with varying resource levels

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Abstract

This paper proposes Particle swarm optimization for resource constrained project scheduling problem with varying resource levels (RCPSPVRL). RCPSPVRL uses resources of limited availability but varying predetermined levels. The activities are of known durations and resource requests, linked by precedence relations. In project scheduling problems, project activities are assumed to have constant resources throughout the entire project duration. In RCPSPVRL, resources are not kept constant, the total project duration is divided in to different time periods, within a particular time period the quantity of resources are kept constant and the quantity of resources can be varied on various time periods. The objective is to schedule the activities in such a way that effective utilization of resources are made by utilizing varying resource levels. RCPSPVRL is tested by using CPLEX ILOG optimization studio and is validated by using PSO on MATLAB 2014.

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1. Introduction

A resource constrained project scheduling problem (RCPSP) contains resources of limited availability, several activities of certain durations and resource requests, linked by successor and precedence relations. [3] The objective is to find a project schedule with minimum duration by assigning a start time to each activity such that the resource availabilities and precedence relations are satisfied.

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Resource-constrained project scheduling problems are the most famous proposed problems in optimization research. As complexity of the problems are considered, designing of efficient algorithms are required for solving the problems in considerable time. On the other hand, this series of topics are generally under project management and industrial engineering and are given much attention in recent decades. Competitive features of today’s world measures the quality and timely development of project schedule. These factors provide much attention in the stream of resource constrained project scheduling problems with their solutions practically and theoretically by academic researchers and practitioners. [3]

2. Serial scheduling scheme

In serial scheduling method, the project scheduling problem is divided to n stages. In each stage, one activity is selected and scheduled at the earliest based on precedence relations, resource availability and priority. Serial scheduling scheme consist of 3 sets namely decision set (Ds), scheduled set (Ss), and completed set (Cs).[1]

The decision set comprises of all activities which are eligible for scheduling ie, the predecessors of all activities present in the decision set are completed. The scheduled set comprises the activities which have already been scheduled. The scheduled set updates on each stage by adding the activities from decision set to scheduled set. The final stage scheduled set describes the project scheduling path.

Procedure of serial scheduling:

1) Start with an empty schedule.
2) Find all activities whose predecessors are zero or completed.
3) Select job from decision set having the highest priority and schedule it as early as possible.
4) The scheduled activity is then transferred to scheduled set.
5) Update decision set.
6) Repeat step 2, 3, 4 until decision set becomes empty.
7) The final stage of scheduled set describes the project scheduling path.

3. Description and formulation of RCPSPVRL

Project planning is the determination of scheduling plan for conducting a series of related activities that are constituents of project. Those project scheduling problems which do not have resource limitations are known as project scheduling problems without resource constrained and if resource limitations are considered in project scheduling problems, such problems are known as resource constrained project scheduling problems (RCPSP). These problem are one of the most complicated problems in operation research which have a considerable progress in developing the exact solution and creative methods for better solutions. Implementation of each model needs different types and quantities of resources.[3] For implementing resource-constrained project scheduling problems each activity $i$ needs $s_ia_k$ unit of resource $k = 1,..., m$ per unit of activity’s execution time ($d_i$). Meanwhile $k$ resource has $b_k$ constraints per unit of time. The parameters ($d_i, r_i, b_k$) are non-negative and determined. The objective of this problem is to determine the start time of each activity for minimizing the project duration. It is obvious that the problem solution are related to activities, logical relations, and considering resource constraints too.

3.1. Assumptions in the RCPSPVRL study:

1) The activities composing a project have certain and known durations.
2) All predecessors must be finished before an activity can start (i.e., precedence constraints).
3) Resources can be of multiple varieties, available in limited quantities and are renewable from period to period (multiple resource constraints) however this study focuses on single resource constraint problems.
4) Pre-determined variations in resources levels are permitted.
5) Activities are non pre-emptive.
6) Managerial objective is to minimize the total duration of project.
3.2. RCPSPVRL formulation

The RCPSPVRL is normally characterized by objective functions, features of resources, and pre-emption conditions. Minimization of project duration is the main objective of RCPSPVRL, while other objectives such as minimization of total project cost are also considered. The classical RCPSPVRL considers renewable resources, non-preemptive activities and minimizing of project duration as main objective.

RCPSPVRL can be formulated as follows:

\[
\begin{align*}
\min \{ \max_{i=1, 2, \ldots, N} F_i \} \\
\text{Subject to} \\
F_i \geq D_i \quad \forall j \in P_i, i = 1, 2, \ldots, N \\
\sum_{i=1}^{N} r_i \leq R_i \quad t = 1, 2, \ldots, F_R
\end{align*}
\]

where N is the number of the activities involved in a project; \( F_i \) is the finish time of activity \( a_i \); \( D_i \) is the duration of activity \( a_i \); \( P_i \) is a set of preceding activities (or predecessors) of activity \( a_i \); \( R_i \) is available amount of resource; \( r_i \) is the amount of resource required by activity \( a_i \); and \( A_t \) is a set of ongoing activities at \( t \).

Formula (1) represents the objective, while formulas (2) and (3), respectively, represent precedence constraints and resource constraints.

4. Particle swarm optimization

Particle swarm optimization (PSO) was developed by Kennedy and Eberhart in 1995. PSO is an evolutionary algorithm that simulates the social behavior of bird flocking to a desired place. PSO starts with initial solutions and updates them from iteration to iteration. Updating of particle represented solutions is achieved through formulated equations that are able to exploit the searching experience of one particle itself or the best of all the particles. Advantages of PSO over other metaheuristic methods includes computational feasibility and effectiveness. PSO shows its uniqueness such as easy implementation and consistency in performance.

The particle-updating mechanism for particle flying (i.e., search process) can be formulated as [4]:

\[
\begin{align*}
V_i(t) &= w(t)V_i(t-1) + c_1 r_1(X_i^l - X_i(t-1)) + c_2 r_2(X_i^g - X_i(t-1)) \\
X_i(t) &= X_i(t) + V_i(t-1)
\end{align*}
\]

\( X_i^l = \{ x_i^1, x_i^2, \ldots, x_i^{M_i} \} \) represents the local best of the \( i^{th} \) particle encountered after \( t-1 \) iterations, while \( X_i^g = \{ x_1^i, x_2^i, \ldots, x_M^i \} \) represents the global best among all the swarm of particles achieved so far. \( c_1 \) and \( c_2 \) are positive constants (learning factors), and \( r_1 \) and \( r_2 \) are random numbers, whose value lies between 0 and 1; \( w(t) \) is inertia weight used to control the impact of the previous velocities over the current velocity. Formula (4) is used to calculate a particle’s new velocity from particle’s previous velocity and the distances from its current position to its local best and the global best. Equation (5) is used to calculate a particle’s new position by utilizing the local best and global best experience of all particles. Equation (4) and (5) also reflect the information-sharing mechanism of PSO.

4.1. Steps involved in PSO algorithm

1. Initialize the swarm of particles to the solution space.
2. Evaluate the fitness of each particle.
3. Update individual and global bests.
4. Update velocity and position of each particle.
5. Go to step 2, and repeat until termination condition.
5. Parameter configurations

The parameters required for priority based PSO are summarized, as shown in Table 5.1. The inertia weight is selected according to the conclusion of Shi and Eberhart [8], that is, 1 is a good choice when the maximum velocity (i.e., \( V_{\max} = 1 \)) is smaller than 2, and 0.8 is a good choice when the maximum velocity (i.e., \( V_{\max} = N \)) is larger than 3. Learning factors \( c_1 \) and \( c_2 \) creates a little bit of difference [9], hence, they are set to 1 as usual. The population size, \( M \) (i.e., the number of particles in the swarm) is usually taken as the number of the non-dummy activities (i.e., \( N \)) in the project, considering that more particles may increase searching success but similarly require more evaluation runs [9].

<table>
<thead>
<tr>
<th>PSO type</th>
<th>Inertia Weight ( W(t) )</th>
<th>Learning Factor ( c_1 )</th>
<th>Learning Factor ( c_2 )</th>
<th>Population size ( M )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Priority-Based PSO</td>
<td>0.8</td>
<td>1</td>
<td>1</td>
<td>Close to ( N )</td>
</tr>
</tbody>
</table>

Tab: 5.1: PSO Parameters

6. Methodology and steps

In this work, two standard RCPSP problems are selected from PSP-LIB for research study. The project scheduling problems are performed on CPLEX. Then the same project scheduling problems are verified by using PSO on MATLAB 14.0.

7. Computational analyses

The project considers renewable resources of single type and consists of several activities with two dummy activities. Each activity has a certain duration, resource requirement, certain successors and predecessors. The successors and predecessors relations among the activities are described with arrow lines.

To investigate the method for RCPSPVRL, consider the project network as shown in Figure 1. Our objective is to find the optimal project schedule. In this problem two time limits are proposed. Resources are varied in both time limits. From time 0 to 4, resource available are 4 units, from time 4 to 9 resource available are 2 units.

![Figure 1: Project scheduling problem 1](image-url)
To investigate the method for RCPSPVRL, consider another project network as shown in Figure 4. Our objective is to find the optimal project schedule. In this problem two time limits are proposed. Resources are varied in both time limits. From time 0 to 7, resource available are 7 units, from time 7 to 17 resource available are 9 units.
8. Results

Various advantages are achieved by using RCPSPVRL. In realistic project scheduling problems, resources are not kept constant. Sometimes the resources at the initial stage of project may be less and it can be increased further to reduce the project duration. In some project scheduling problems, parallel activities at some stage may be less, while in some stages parallel activities are more, by using RCPSPVRL technique, both the problems can be solved effectively by suitably assigning the time limits and resource levels.

9. Conclusion

From computational analysis, it can be concluded that RCPSPVRL can be used to solve problems with various resource demands, which have various advantages.

A PSO based method including its corresponding framework is proposed for solving the RCPSPVRL in terms of finding the better time schedule by implementing the method of varying resource levels, more over optimum utilization of resources can also be found out using RCPSPVRL.

Particle representation of activities, priorities based on which a feasible schedule can be definitely produced is opted for PSO based approach for solving RCPSPVRL.

Small RCPSPVRL problems are formulated as linear programming model on CPLEX. By using CPLEX solver the best solutions are obtained. The same problems are solved by PSO, and same solutions with different project schedule are obtained as compared to CPLEX.

The time taken for solving NP hard problems on CPLEX solvers is very high, while the same NP hard problems can be solved by using PSO technique in less time. Hence PSO based RCPSPVRL problem can be used for solving NP hard project scheduling problems in a better manner.

The computational analysis shows that the PSO based approach for RCPSPVRL is better as compared to performance analysis on CPLEX. The PSO based approach provides an efficient and easy to implement alternative to analyze and achieve the RCPSPVRL.

RCPSPVRL is successfully implemented in project scheduling problem with the help of CPLEX optimization studio. MATLAB 14 is used to verify RCPSPVRL and is successfully completed.

10. Scope of future work

There is a wide scope in future for scholars to explore the current research field. The present work is performed on single resource constrained project scheduling problem with varying resource levels. This same idea can be implemented on multiple resource constrained project scheduling problems (MRCPSP).

Currently we are assuming that, all the different types of resources are available throughout the project duration. In exact case, this may not happen and hence the MRCPSPVRL can be modified by incorporating a new constraint on resources. ie, some types of resources are available only for some time periods. Optimum time schedule has to be developed based on new constraints.

Further scope in this area will be by incorporating WET (weighted earliness tardiness) in RCPSPVRL and MRCPSPVRL.

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References


