A HEURISTIC IMPROVED METHOD BASED ON THE PRIORITY FOR CONstrained PROJECT SCHEDULING PROBLEM WITH FUZZY PARAMETERS

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Abstract. In this research at first some of the most important previous studies in the field of fuzzy project planning and its various solving procedures are reviewed and introduced. Then after introducing the problem model and considering its theories, one of the most creative approaches for solving the Constrained and definite Project Scheduling Problem has improved and deployed with allowing time parameters and fuzzy resource to solve the problem. With utilizing one of the presented approaches in previous researches the needed operations for computing the priorities were improved and finally the proposed algorithm in the total form and ability to solve the mentioned fuzzy problems in different dimensions were offered and described. After programming of the proposed algorithm with visual c#, 120 problem instances with different properties was solved by the algorithm and the priorities were ranked and analyzed with respect to its results. With respect to use a way for ranking fuzzy numbers in this algorithm, some of the different presented ways in previous researches and categories have been also reviewed. At the end some suggestions for developing the model and applying the other theories in problem model were presented for further researches.

Keywords: Project Scheduling With Constrained Resources, Critical Path Method, Triangular Fuzzy Number, Heuristic Rule Based On Priority, Fuzzy Project Planning, Ranking Of Fuzzy Numbers

INTRODUCTION

Project Scheduling is one of the most important and widely used areas in industrial engineering planning. Application of theoretical issues of this area in a wide scope of practice and variety of the researches in this field shows the importance of this area more than before. Project scheduling problem includes a wide range of problems and many classifications are presented in this regard. For each one of the different types of project scheduling problem, various methods have been studied by the researchers. These methods include accurate, heuristic and meta-heuristic methods. Since this problem belongs to the group of the difficult problems, many heuristic and meta-heuristics are presented for different models of this problem and some comparisons of these approaches are made for some problems. Noting the importance and applicability of the problem and its application in practice, the constraints of the real world were added to this problem. The uncertainty of some problem parameters is among these constraints. In the real world, the parameters of the problem are estimated using past data and experiences and then are used in a certain form in the problem, but in many real cases due to lack of information or access to the similar data, the exact estimation of the parameters is impossible. With the introduction of fuzzy theory and its applications in the last years of planning and given the conducted researches in this area and mentioned constraints, the importance of this theory appears for modeling and solving various problems of project scheduling. Among important factors in the project scheduling we can point to the time needed for playing activities, amount

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of access to different resources, activity requirements to resources, delivery times and so on. In this study, fuzzy theory and a heuristic method is used to solve this problem. In previous researches, parameter of the time to enforce activities was assumed uncertain and based on that assumption and by using methods of project scheduling and fuzzy theory, heuristic and meta-heuristic methods are presented. In this study, after the introduction of the problem and a review on some of the most important researches conducted on fuzzy project scheduling, we use the Priority-Rule-Based Heuristic approach which is one of the oldest and most important heuristic approaches to solve this problem. In addition to apply the new fuzzy parameters in the problem, some improvements have been made in the procedure in terms of fuzzy computation. Then this method has been coded and various problem instances have been solved to show the efficiency of the algorithm. Finally the obtained results of the different samples are analyzed for different priorities.

**Research record**

Proponents of the fuzzy theory for the activities time believe that the probability distribution for activity time is uncertain due to the shortage or lack of data from the past. Since the activity times must be estimated by experts and are often unique and single, project management encounters uncertain and mental (ambiguous) judgments. In situations and functions that involve uncertainty in an ambiguous way, the subject literature on scheduling with fuzzy sets recommends using fuzzy numbers instead of stochastic variables for modeling the activity time. These amounts of uncertainty use membership functions based on Possibility Theory instead of the probability distributions.

Normally the path output of fuzzy scheduling will be fuzzy program which shows the beginning and end of fuzzy activities. A fuzzy program shows degrees of certain freedom in a predicted program and necessary management precautions in constrained conditions noted in terms of late or early beginning of activities. (Dorn et al, (1995)). In these situations, the final fuzzy schedule implies a certain multiple plan. Hapke and Slowinski, (2011) studied the important researches in fuzzy project scheduling. Now the subject literature and researches on fuzzy project scheduling are at their initial phase. (Hapke et al (1994) and (1999), Hapke and Slowinski,(1996,2000), Ozdamar and Alania (2000), Wang (1999, 2002, 2004)). Studying Resource-Constrained Project Scheduling Problem started with Hapke(1994), and Hapke and Slowinski(1996). They developed the priority rules in scheduling methods based on sequential and parallel scheduling for fuzzy parameters. Hapke and Slowinski(2000), studied the application of simulated annealing (SA) for solving multi-objective fuzzy RCPSP. Their method was a combination of simulated annealing and Pareto (Jackowich and Xiak) to solve certain multi-objective problem. Ozdamar and Alania (2000), examined the software development projects and proposed a zero-one nonlinear programming model and a mixed one and used heuristic approaches. Their model considers the uncertainty associated with the activity time and network topology. Activities can be performed in different enforcement modes with related fuzzy times. The objective function is the minimization of the project time. They applied four Priority-Rule-Based Heuristic approaches: Minimum Standard Slack, Latest Finish Time (LFT), Maximum Instant Successive Activities, and the minimum risk. Wang (2002) proposed a fuzzy search approach to solve the problem with the objective of minimizing the risk of the program. Wong (2004) proposed a genetic algorithm to solve the problem with the objective of maximizing the performance in the worst conditions of the program. Tarun Bhaskar et al (2011) proposed a new Rule-Based heuristic method for RCPSP with fuzzy times. They used parallel scheduling method and proposed a new priority based on the critical degree of the activities and consumption measures of resources. At each decision point of the parallel scheduling process they determined feasible activities subsets according to precedence and resource constraints and computed their proposed priority values for the subsets. Subset with the highest priority value is chosen for scheduling at that time point (decision point). The critical degree of each subset
activities means their distance from the critical time of the project. The critical time of the project without resources constraints was computed with using the comparison and ranking methods based on the fuzzy numbers distance. Factor of the resource requirements for each subset is computed by dividing the amount of resources required for activities on the available amount of that resource. They also computed the weights for resource requirements factor and the critical degree of activity of each subset based on employing the constraints for each resources and finally computed their own proposed priority value and At the end they presented the proposed method in an example which includes seven activities with fuzzy times in a triangular shape and applied on 21 problems from Project Scheduling Problem Library and the obtained results were compared in a certain form. Also some researches are done for the time-cost trade-off problem with fuzzy parameters. Maan et al (1995) by adapting the concept of α-cut, optimism of decision maker index and Fuzzy Pert method proposed a way to analyze TCTP with triangular fuzzy times. Arıkan and Gungor (2001) employed a fuzzy goal programming method for solving TCTP with multiple objectives; also some methods have been presented based on genetic algorithm for fuzzy TCTP problem such as Leo et al (2001) and Eshtehardyan (2009). Chen et al (2011) proposed a new approach for TCTP in the fuzzy environment. Several previous methods may encounter problems in computing the latest fuzzy starting time of activities. They proposed their method by combining the concept of α-cut, the development principle of Lotfi Zadeh (1978) and linear programming. Two parametric programming models used for formulating the upper and lower α-cut of minimum fuzzy cost of break function. Results obtained from these two mathematical programming models, creates the minimum fuzzy break cost function, also optimal activity times at various levels of uncertainty is obtained. At the end they proposed two examples by regarding triangular and gaussy fuzzy numbers to show the validity of their method and showed the results. Their method is applicable for more complicated types of fuzzy numbers such as L-R numbers.

Different methods in articles are done for the critical path computations (CPM) in the condition of fuzzy activity time. In these articles, there are two general approaches for fuzzy CPM. The first approach converts all fuzzy data (activities time) to a certain data by one of the defuzzification methods then the certain obtained problem CPM is determined by conventional methods or linear programming and the critical path. Finally by replacing certain values of time with their fuzzy values the CPM time is obtained as a fuzzy number and the critical degree of each path of the network is obtained by definition of a simple index. Chen et al. (2008) presented this approach using the Yager ranking index (1981) and finally obtained the total time of CPM using an example as a fuzzy number. Also they use Yeager's index to calculate the relative critical degree of a path that in this method the critical degree for the critical path (s) in definitive problem is assumed 1. The second approach using the Lotfi Zadeh's development principle (1965) and using the α-cut concept, calculates the total time of CPM for each of the different values of α, and therefore the time of CPM is obtained as a fuzzy number. Chen (2007) by using this approach and proposing related linear programming model computed the upper and lower bounds of project time for a certain amount of α. Then by solving a problem they solved the related model for different values of α and obtained the total project time as the form of an estimated fuzzy number and computed the critical relative degree of each path using yagers index and then compared the results of their method with that of Chanas and Zielinoński (2001). Chanas (2001) first studied CPM by assuming the activity times as a time span. And by presenting a theorem proved the critical condition of a path. Then by generalizing the problem to the fuzzy time problem and relating the fuzzy problem to the relevant α-cut problem (range) they proposed and proved a theorem. Then, based on this theorem they proposed an iterative algorithm for computing the critical degree of the various paths in fuzzy problem and for certain types of fuzzy numbers (L-L) this algorithm was changed to linear programming model and by providing an example the efficiency of both algorithms was shown. The path that has the most critical degree is known as the most critical path. Zarei, et al (2011) did a similar approach with that of Chen (2007) based on the analysis of AOA network event and then by offering four
linear programming models they obtained the high and low limits of the earliest and latest time of occurrence of each event for each values of α and defined the critical degree of network paths using criticality index of each knot. By using method of Chanas and Zielinski (2001) Haji Yakhchali (2012) obtained the critical degree of network paths and then proposed a counting algorithm to compute the critical degree of the activities in the form of minimum path(s) degrees which include that activity and finally by presenting a numerical example tested the efficiency of this method in a number of different activities. In this research a similar method like that of Chen (2008) was used with the exception that in addition to finding the critical path, the earliest and latest time of the events are obtained in the form of fuzzy and the method of Ming et al (2000) is used for making definite and the comparison of fuzzy numbers. If the second approach (using of α-cut computations) is used for CPM computations beside the forward computation, backward computations can be similarly used to calculate the values of LFT, LST, TF and ... and the above values as an approximate fuzzy number can be obtained. Backward computation is impossible due to direct subtraction of fuzzy numbers and if fuzzy subtraction operator (bounded) is used, the fuzzy values may not be obtained or for the time parameters such as LFT, negative values may be obtained which are unacceptable. For these reasons, the method of (Haji and Soltani 2007) is used for fuzzy subtraction operations and computation of LFT, LST, float values of activities and other fuzzy priorities.

An Improved Algorithm for RCPSP with Fuzzy Parameters

Here we attempt to improve Hapke and Slowinski’s method (1996) with some corrections and add new fuzzy parameters to the problem. Their proposed method is not systematically capable of coding all problems and its introduced method for the subtraction of fuzzy numbers in computing LST and LFT values and also float values of activities is encountered with difficulties. Actually the result of this subtraction is not necessarily a fuzzy number and can even obtain negative values for time parameters such as LFT which are infeasible. Soltani and Haji (2007) proposed a fuzzy scheduling method. Their method computed forward computations directly by comparison of fuzzy numbers but they proposed backward computations with some corrections on the fuzzy operations. With assuming positive trapezoidal fuzzy numbers, they proposed a mathematical model to calculate the result of fuzzy numbers subtraction and then by making linear and solving the model they obtained a general answer to subtraction of fuzzy numbers in backward computations and showed that the result of the subtraction is a positive trapezoidal number. Finally, by solving an example including 9 activities with AOA network, they obtained LFT, LST, and float values of activities in the shape of a positive trapezoidal number. Therefore we use the method of Soltani and Haji (2007) proposed for fuzzy CPM computations. However, this method may encounter problems in problems that at least have one fuzzy resource parameter because the defined subtraction operation is not the reverse of fuzzy addition and therefore as it is shown in the results and proposed algorithm, the proposed priority based method may not find any answer (the problem becomes infeasible). However when all the resource requirements parameters and available values of resources are certain if the problem is feasible at first then it will lead to answer for all the priorities. Generally in this method the fuzzy numbers should be compared in three different situations. The first situation is during forward computation in fuzzy CPM in which the earliest feasible time of activities with respect to precedence relations should be obtained as a fuzzy number. The second situation occurs in the backward computations during the computation of LFT and LST for activities and also the computation and comparison of the other fuzzy priorities. Finally the results obtained from different fuzzy priorities that each of them is a fuzzy number should be compared with each other. In this study, the method of Ming (2001) is used for comparing fuzzy numbers which will be introduced in the following. Now we describe the proposed algorithm with parallel scheduling approach for RCPSP problem by considering requirements and resources available values and also activities time in a form of positive triangular fuzzy number.
Fuzzy Parallel Algorithm:

This algorithm is done in three general stages. At first stage the earliest start time of the project activities is determined with respect to precedence relations, then the earliest finish time of the project is obtained as a triangular number. At the second stage first backward computations are done and the latest finish time of activities with respect to upper limit of finish time of project and precedence relations is obtained. These computations are carried out according to the method proposed by Soltani and Haji (2007). Then the values of 11 fuzzy priorities in Table 1 are computed for all activities and on the basis of the related priority rule, a sequence of activities is computed for each priority. In the third stage the parallel scheduling is done for each priority and 11 obtained sequences from the second stage each one as an entry enter to the third stage in the form of an array and the parallel method is done for 11 different priority rules and at each time the result is calculated by using the parallel method for the related priority. Finally the answer obtained from the first stage is shown as the earliest finish time of the project and the answers obtained from the third stage are shown as obtained results of different priorities in output of the algorithm.

With regard to the figure 1, first the S collection is identified. S collection includes activities that does not have any precedent activities (R_i is the collection of precedent activities of activity i). In the AON network, the S collection includes activities in which only dummy start activity is their precedent activity. After identifying the S collection, the G collection contains activities that all of its precedent activities exist in S collection (\( R_i \subseteq S \)), this collection is similarly identified and the earliest start time of its activities is computed according to the precedence relationship. Then similarly the earliest start time of other activities that all of their precedent activities have been scheduled is computed. This process continues until finding the earliest start time for all activities. Finally the maximum amount of the earliest finish time of activities is computed and stored in the parameter t_c as the earliest completion time of the project. In all the algorithm stages, the maximum and minimum operation of triangular fuzzy numbers is computed using Ming et al (2000) method as following:

If A, B are two positive triangular numbers first the mean value is calculated for them:

\[
A = \frac{(a_1 + 2 \times a_2 + a_3)}{4} \quad (1)
\]

\[
B = \frac{(b_1 + 2 \times b_2 + b_3)}{4} \quad (2)
\]

If \( A > B \), then \( B < A \) & vice versa. If \( A = B \), then the following formula is calculated for each one:

\[
A_2 = \frac{(a_3 - a_1)}{2} \quad (3)
\]

\[
B_2 = \frac{(b_3 - b_1)}{2} \quad (4)
\]

If \( A_2 > B_2 \) then \( B > A \) & vice versa. If \( A_2 = B_2 \), then \( A = B \).
In the Second Step which includes the backward calculations, by using the data obtained in the first step the values of 11 fuzzy priorities for each activity are calculated and for each priority, the activities are arranged according to values of the respective fuzzy priority. For example, calculating LFT, for the activities in the second step with Haji and Soltani Method (2007) are done as follows:

\[
\text{LFT}_i^2 = \max \left\{ 0, \min \left\{ LFT_i^3 - a_i^2 | \forall l \in \eta_i \right\} \right\}
\]

\[
\text{LFT}_i^3 = \max \left\{ 0, \min \left\{ \min (LFT_i^2 - a_i^2 | \forall l \in \eta_i), LFT_i^3 \right\} \right\}
\]

\[
\text{LFT}_i^1 = \max \left\{ 0, \min \left\{ \min (LFT_i^1 - a_i^1 | \forall l \in \eta_i), LFT_i^2 \right\} \right\}
\]

Then, as shown in figure No. 2, the third step of algorithm is started. The parallel scheduling of activities are accomplished based on the obtained arrays of second step; therefore, there are 11 different input arrays in the third step which will result an answer as a final time of the project for each of inputs. During algorithm coding, this step was considered as a function which its inputs are the arrays obtained in the second step and finally the output of function for different
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inputs displayed as a result of different priorities. At this step, first the used parameters and sets are introduced. Set SA includes the activities which are scheduled until the current time. Set C shows the completed activities in current time and set Q includes the activities which can be scheduled during the current time with respect to precedence relations. As the two previous steps, a_i is the time of completing the activity i and b_j shows the available value of resource j within the time periods and c_{ij} shows the use of activity i from resource j during each completion period of activity i. The full remarks of figure 2 are stated in appendix.

Determining array B as the input

initializing the values: introduction of the empty Sets T, C, SA1, AS, Q & min-index and parameter t

Put the entire activities of Set S in Set Q

Arrange set Q with respect to array B. Empty Set T and put Counter = 1

Define parameter QC and put QC = |Q|

Select the first activity of set Q-T

\[ c_{ij} < b_j - \sum_{j=1}^{m} c_{ij} \]

Yes

\[ t_i^f = t + a_i \]

Counter = counter + 1

Add activity i to set T

Counter = counter + 1

No

Delete i from Q and add it to SA and SA1

\[ b_j = b_j - c_{ij} \]

j = 1, ..., m

QC # counter

Yes

I SA1 I = 0

1250
Masmudi and Hit (2013) present this procedure at the state of dependency between the parameter of resource workload and the activity times. According to the start and finish time of an activity, the membership function of activity existence between these two times is generated and the fuzzy membership function of workload will be calculated based upon that membership function at each moment and if the resource constraints are met, the related activity are scheduled at decision time with respect to priorities arrangements. At this method, the resource requirements are not determined at first and are dependent to the fuzzy start and finish time of the respective activity. At last, by solving an applied problem instance, they obtained the result of the algorithm for a priority. Definition of workload activity function is dependent to the start and finish time of activity and should be recalculated for various decision times which leads to more time complexity of algorithm. The workload of each activity is also calculated in different form with respect to the overlapping type of fuzzy start and finish times of that activity.
Computational results

The selected problem instances include 60 fuzzy problems which each one has 20 activities. Each of six unique precedence networks includes 5 problems with two resources and 5 problems with three. At the same, 60 problems, each includes 20 activities with certain parameters of time and resources were chosen and their output reviewed and analyzed. Each of priorities has been recognized as the best priority in the output of some problem instances. The priorities can be ranked with respect to the number of problems in which those priorities have the best result. At last the ranking of priorities was identified based on the results of 120 problem instances (definitive and fuzzy).

Table 2. Ranking of priorities with respect to 120 problem instances (definite and fuzzy).

<table>
<thead>
<tr>
<th>Rank</th>
<th>Priority name</th>
<th>The number of best answer to 120 problem instances</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>61</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>53</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>48</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>42</td>
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<tr>
<td>5</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>10 &amp; 5</td>
<td>39</td>
</tr>
<tr>
<td>7</td>
<td>11</td>
<td>37</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>34</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>31</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>26</td>
</tr>
</tbody>
</table>

Conclusions and suggestions

This procedure develops a heuristic approach for solving the definitive RCPSP to the fuzzy problem which is based on fuzzy priorities, therefore, by describing the new priorities for activities it can be easily(with little correction) obtained the result of algorithm for the new priorities and identify the best priorities after solving different problem instances. It is suggested by increasing the coding capability, the larger problem instances are solved, then meantime the comparison of priorities for various problems and more accurate ranking of them, the run-time efficiency of algorithm in terms of complexity to activity numbers and other parameters will be evaluated. Certainly, by increasing the number of proper priorities, it is possible to improve the average deviation of answers from CPM time. It is suggested that by solving a high number of fuzzy and definitive instances with various dimensions, the priorities ranking in fuzzy procedure is done separately for definitive and fuzzy problems and the overall results of all instances are compared with the result of fuzzy and definitive instances. It is possible to study the possible convergence of priorities ranking for these two types of problems by comparing the results of definitive and fuzzy instances and by considering the results of all instances analyze the advantages of priorities in general. This algorithm can be developed by adding more definitive and fuzzy parameters to the problem such as set up and delivery time. Also delay times in precedence relations are considered zero and this algorithm shall be developed in general case with considering the positive values with some corrections. In addition to using the various priorities to calculate the activity orders, it is possible to apply simulation to create more activity orders. In this way, if the resource parameters are fuzzy, it is possible to reduce the proposed algorithm limitation for finding the answer (at least one answer).

Appendix

Remarks of Figure No. 2:
After receiving the input array B and introducing the used sets, initially, the entire activities of set S will be transferred to Set Q. in fact; the entire activities of Set S are schedulable at the
current zero time with respect to precedence relations. Then the Q activities are arranged based on the related arrays and selected for scheduling respectively. If the selected activity does not violate the resource constraints, then it is scheduled and its finish time is calculated and deleted from Set Q and transferred to Sets SA & SA_i. Otherwise, the next activity from the arranged set Q will be selected for scheduling again. This procedure is accomplished until the entire activities of set Q are studied. After scheduling of each activity, the available amounts of resources are changed, and this change is accomplished by the Haji and Soltani fuzzy subtraction operations (2007). Then the algorithm stopping condition is studied (|SA| = n). With meeting this condition, all activities are scheduled and the maximum finish time of the last activities is reported as the project finish time. If this condition fails, the next condition is considered (|SA_i| = 0). This condition identifies the infeasibility of input problem or changing to infeasibility of a feasible problem during the algorithm procedure, stops the algorithm and reports the problem infeasibility for the related priority (related array). This condition studies the emptiness of Set SA_i, in fact after passing the previous condition, the entire activities of the project are not scheduled yet, and in this situation the emptiness of set SA_i shows that there is no time to select as the current time, hence there is no possibility for remaining activities to schedule and the problem will be infeasible. If this condition fails, the minimum completion time of set SA_i activities are determined as the current decision time. At this time, due to completion of one or more activities, the available amount of resources is changed at the current time which is applied by the formula b_j = b_j + c_j, j = 1, …, m. The activities with the minimum completion time value in set SA_i are placed in min-index set and this formula is applied for activities of min-index. Then, the min-index activities which are completed in the present current time are deleted from set SA_i and transferred to the set C. By changing Set C, the set of schedulable activities in the current time(Q) are changed and from the unscheduled activities which are not in set Q, if the precedents of an activity is located in Set C, this activity will be added to Q. At last, by considering the condition of non-emptiness in Set Q, it will be returned to ordering step of set Q and the activities are reselected in selection orders and scheduled considering the resource constraints. If at this step, Q is empty, it means that no activity could be scheduled at the current time considering the precedence relations, therefore the algorithm will be returned to the respective step to find the new current time and this procedure will be continued up to the time that set Q becomes non-empty. At this manner, by repetition of this procedure, the algorithm shall accomplish the scheduling of activities in parallel and based on the respective priority and if the problem is feasible and remains feasible during the algorithm, the final answer for that priority is reported as a triangular fuzzy number.

REFERENCES