Some heuristic rules for scheduling single and multiple resources constrained projects

M.A. Shouman [a], M.S. Ibrahim [b], M. Khater [b] and A.A Forgani [b]
[a] *Research and Decision Support System Dept., Faculty of Computers and Informatics, Zagazig university, Zagazig, Egypt*
[b] *Industrial Eng. Dept., Faculty of Eng., Zagazig university, Zagazig, Egypt*

Single and multiple resource (s) constrained project scheduling problems belong to the set of complex combinatorial problems. Such structure problems have infinite decision variables and alternative solutions and there is no solution methodology that will perform best for scheduling all projects configurations. In the current study fifty-five heuristic rules are introduced for scheduling projects. These heuristic rules are tested for single and multiple resource (s) constrained projects using fifty test problems. The performances of the scheduling process using these heuristics for the considered projects are discussed and evaluated. Results are promising and general remakes and tendencies are highlighted.

تعتبر جدولة المشروعات ذات الموارد المحددة الأحادية والمتعددة من المشكلات المعقدة فى حلها حيث أن هذه المشاكل بها عدد لا نهائى من كل من المتغيرات التى تحتاج إلى اتخاذ قرار والبدائل التى يمكن اعتبارها حلول ممكنة للمشكلة ، هذا بالإضافة إلى أنه ليس هناك أسلوب محدد يمكن التعامل من خلاله مع البنية ذات السمات المتعددة للمشاريع المختلفة. فى هذا البحث تم استحداث عدد خمسة وخمسون قاعدة استكشافية لجدولة المشروعات أحادية ومتعددة الموارد المحدودة وقد تم تجريب هذه القواعد على عدد خمسة و خمسون مشروع من المشاريع المستخدمة فى أبحاث سابقة كمشروعات مرجعية. تم تقييم هذه القواعد فى الجدولة وقد أظهرت الدراسة مدى كفاءة وفاعلية العديد منها فى جدولة المشروعات.

Keywords: Single and multiple resource problems, Scheduling projects, Heuristic rules, Constrained resource projects

1. Introduction and background

Resource-Constrained Project Scheduling Problem (RCPSP) can be stated as a single project consists of a number of *N* activities where each activity has to be processed in order to complete the project. The activities are interrelated by two kinds of constraints. First, precedence constraints force activity *j* not to be started before all its immediate predecessors have been finished. Second, performing the activities requires resources with limited capacities. Altogether there is a set of resources while being processed, activity *j* requires r_{jk} units of resource k € R *in* every time instant of its non-preemptable duration p_j, $r_{j,k}$, and R_k are assumed to be nonnegative and deterministic. The objective of the RCPSP is to find precedence and resource feasible completion times for all activities such that the make span of the project is minimized. Ever science the development of critical path methods, the research has been conducted on Single and Multiple Resource-Constrained Project Scheduling Problems (SRCPSP, MRCPSP). The main objective of this work is to study and find some heuristic rules for scheduling all projects configurations for single and multiple resource-constrained projects.

Since its advent as mentioned by Pritsker et al. [1], the MRCPSP has been a very popular and frequently studied NP-hard optimization problem Blazewicz et al. [2]. The last 20 years have witnessed a tremendous improvement of both heuristic and exact solution procedures as surveys given in Demeulemeester and Herroelen [3], Hartmann and Kolisch [4, 5], Herroelen et al. [6], Kolisch and Padman [7], and Ozdamar and Uiusoy [8] due to the fact that the MRCPSP "is one of the most intractable problems in operations Research". It has recently become a popular playground for the latest optimization techniques including virtually all-local search paradigms Mohring et al. [9]. The categorization of solution procedures for scheduling problem are classified as cited in Rainer Kolisch and Sonke Hartmann [10] into priority rule-based-X-pass methods, classical meta-heuristics, non-standard meta-heuristics, and other heuristics. In X-pass methods a priority order is given for each specified activity included in the project under either a serial and/or parallel scheduling generated strategy. X-pass methods have been summarized in many researches [11- 37].

Genetic algorithms, tabu search, simulated annealing, and ant systems are considered as well known meta-heuristic paradigms. In genetic algorithm the project activity list is presented by a gene that determines whether the serial or parallel schedule generated strategy is to be used for transforming an activity list into a schedule. The choice of the more successful scheduling strategy is left to the fittest mechanisms. Genetic algorithms have been summarized in many researches [38-45]. Tabu search technique is considered as essentially steepest decent/mildest ascent method. It evaluates all solutions of the neighborhood and chooses the best one, from which it proceeds further. Tabu search techniques have been summarized in Artigues et al. [46], Klein [47], Nonobe and Ibaraki [48], Thomas and Salhi [49]. Simulated annealing is considered as a search space methodology where it starts with initial solution and a so-called neighbor one is generated by pertur being the current one Simulated Annealing (SA). Valls et al. [50] test a simulated annealing method in a paper that focuses on forward-backward improvement. The neighborhood definition is taken from Valls et al. [51] where a neighbor is constructed by selecting the next activity either in the order of the original solution or by biased random sampling. Ant systems. Merkle et al. [52] present the first application of ant systems a meta-heuristic strategy developed by Dorigo et al. [53] to the RCPSP. In their approach, a single ant corresponds to one application of the serial SGS. The eligible activity to be scheduled next is selected using a weighted evaluation of the Latest Start Time (LST) priority rule and so-called pheromones which represent the learning effect of previous ants. A pheromone value T_{ij} describes how promising it seems to put activity j as the ith activity into the schedule. Further features of the approach include separate ants for forward and backward scheduling and a 2-opt-based local search phase at the end of the heuristic. In non-standard meta-heuristic approaches the solution methodology is based on search space area but without using the traditional or classical meta-heuristic schemes. There methodologies can be classified into local search oriented approaches Fleszar and Hindi [54], Palpant et al. [55], Valls et al. [56] or population based approaches such as Debels et al. [57], Kochetov and Stolyar [58], Valls et al. [45], and Valls et al. [50]. Some other heuristic approaches are presented and cannot be classified as mentioned by Rainer, Kolisch, and Sonke Hartmann [10] as X-pass construction methods or meta-heuristics such as forward–backward improvement techniques presented by Tormos and Lova [59, 60, 61], Valls et al. [50] or such as presented by Artigues [46], Möhring et al. [62], and Sprecher [63].

1.1. Schedule generation schemes

Schedule Generation Schemes (SGS) are the core of most heuristic solution procedures of RCPSP and MRCPSP. SGS start from scratch and build a feasible schedule .Two different SGS are available. Serial SGS based on activity incrementation and parallel SGS based on time incrementation [1]. Priority rule based heuristics employ one or both of the SGS in order to construct one or more schedules. The priority rule itself is used in order to select an activity j from the decision set D_J based on a value V (j) and of an objective starting whether the activity with the minimum or the maximum value is selected. In case of ties, one or several tie broking rules have to be employed.

Priority rule based heuristics combine priority rules and schedule generation schemes in order to construct a specific algorithm. If the heuristic generates a single schedule it is called a single pass method, if it generates more than one schedule, it is referred to as multi-pass method. Many possibilities to combine schedule generated schemes and priority rules to a multi-pass method. The most common ones are multi priority rule methods, forward backward scheduling methods, and sampling methods. There has been an over whelming amount of research on priority rules for scheduling problems such as [64- 73]. Priority rule can be classified according to different criteria based on network topography and configurations such as time, resources, serial or parallel SGS, latest finish, latest start, minimum slack, most total successors, resource scheduling methodology, shortest processing time, worst case slack, …etc .The priority rules may be static or dynamic where the value assigned to activity may changeable during the scheduling vexations or not. Local or global rules based on the information used in prioritizing the activity, where it will be local when it is based one activity information and it will be global when it is based on project information. The rules also may be lower or upper bound based on the minimum objective function values assigned to each activity.

In the current work fifty-five heuristic rules are proposed and tested for scheduling process of single and multiple resources constrained project-scheduling problem (SRCPSP, MRCPSP). These heuristic rules are integrated in a proposed algorithm for scheduling process of either SRCPSP or MRCPSP. This proposed algorithm is designed in a software program using visual basic 6 for evaluation the priority rules for each activity in each project. The algorithm is used for schedule each project using all the considered rules and select the best schedule based on the minimum achievement of completion time. The necessity to such proposed algorithm is that no heuristic rule will perform the best for all variability's of project configurations. In this suggested algorithm multi priority rule methods are employed SGS several times. Each time a different priority rule is used. In such structure, the rules are used in the order of descending solution quality.

1.2. Proposed heuristic rules

R1- MROT

This rule determines the maximum multiple activity resources over time value assigned to the activity it controls through the network on any one path. The mathematical formula for MROT is

$$\text{Max of } \sum_{i=1}^{N} \sum_{j=1}^{L} \sum_{k=1}^{M} R_{ijk} / T_j \, .$$

R_{ijk} is the resource type k required for activity j,
T_j is the time of activity j,
L is the number of activity on path i,
M is the resource types under consideration, and
N is the number of paths linked to the activity.

R2- MACTRES

This rule determines the maximum multiple activity resources value assigned to the activity it controls through the network on any one path. The mathematical formula for MACTRES is

$$\text{Max of } \sum_{i=1}^{N} \sum_{j=1}^{L} \sum_{k=1}^{M} R_{ijk} * T_j \, .$$

R3- MTIMRES

It is the sum of MACTRES and the maximum time that the activity controls through the network on any one path. The mathematical equation is

$$\text{Max of} \sum_{i=1}^{N} \sum_{j=1}^{L} \sum_{k=1}^{M} R_{ijk} * T_j + \text{Max of} \sum_{i=1}^{N} \sum_{j=1}^{L} T_j \, .$$

R4- MGENRES

This rule is a modified version of MTIMRES where the project schedule can be generated using combination of the maximum time that the activity controls through the network on any one path and MACTRES rule with various weightings values. The Mathematical Formula for MGENRES is

$$MGENRES = W\,(MACTRES) + (1-W)\,(ACTIM)$$

When W=0, *MGENRES* will be ACTIM rule while when W=1, MGENRES will be *MACTRES*.

R 5- MACROS

This rule determines the maximum multiple activity resources value it controls through the network on any one path. The mathematical formula is,

$$\text{Max of } \sum_{i=1}^{N} \sum_{j=1}^{L} \sum_{k=1}^{M} R_{ijk}.$$

R6- SOTAMR

SOTAMR value of an activity is calculated as the maximum sum of time and resources that an activity controls through the network on any one path.

$$\text{Max of } \sum_{i=1}^{N} \sum_{j=1}^{L} \sum_{k=1}^{M} R_{ijk} + \text{Max of } \sum_{i=1}^{N} \sum_{j=1}^{L} T_j \ .$$

R7- WMTMROS

This rule is a modification version of MTMROS where the project schedule can be generated using combination of the maximum time that the activity controls through the network on any one path and MTMROS rule with various weightings values. The Mathematical Model for MTMROS will be

WMTMROS = W (MACROS) +(1-W) (ACTIM).

When W=0, WMTMROS will be ACTIM rule while when W=1, WMTMROS will be MACROS.

R8- MROT-ACTIM

This rule is a weighted sum of MROT and maximum time that the activity controls through the network on any one path.

MROT-ACTIM = W (*MROT*) + (1-W) (ACTIM).

When W=0, MROT-ACTIM will be ACTIM rule while when W=1, MROT-ACTIM will be MROT.

R9- MROT-MACTRES

This rule is weighted sum of both MROT rule and MACTRES rule the mathematical model will be:

MROT-MACTRES=w (MROT)+(1w)(MACTRES).

When W=0, MROT-ACTRES will be MACTRES rule while when W=1, MROT-ACTIM will be MROT.

R10- MTG2

Combining different weights of MTMROS and MGENRES generates this criterion MTG2. The project completion time is then calculated for each weighted combination and the shortest schedule is considered as the best schedule. The steps of MTG2 is as follows:

1. Perform *MTMROS* calculations until the best schedule I obtained.
2. Repeat step1 using *MGENRES* criterion and find the best schedule 2.
3. The criterion *MTG*2 for each activity is estimated based on weighted values its MTMROS and MGENRES values in step1 and 2, respectively. In other words the criterion MTG2 of activity is estimated as.

*MTG*2= w (*MTMROS*) + (1-w) (*MGENRES*)

Where (*MTMROS*) = *MTMROS* value of activity i (*MGENRES*) i = MGENRES value of activity i at the best schedule.
W = assigned (0<W<1).

4. Assign a weight W to calculate *MTG*2 for each activity, Rank activities in a decreasing order according to their *MTG*2 values.
5. The project duration is calculated for this weight.
6. Repeat step 4 and 5 for different values of W and the best schedule is determined.

R11- TRTRR (Time Ratio To Resource Ratio)

This rule is the ratio of the sum of activity time and time of all sons to the sum of activity resources and resources of all sons. The mathematical formula is

$$\frac{T_i + \sum_{j \in NF_i} T_j}{\sum_{k=1}^{M} R_{ik} + \sum_{k=1}^{M} \sum_{j \in NF_i} R_{ik}},$$

where NF_i = set of activities that follow activity i

R12- RRTTR (Resource Ratio To Time Ratio)

This rule is the ratio of the sum of activity resources and resources of all sons to the sum of activity time and time of all sons. The mathematical formula is

$$\frac{\sum_{k=1}^{M} R_{ik} + \sum_{k=1}^{M} \sum_{j \in NF_i} R_{ik}}{T_i + \sum_{j \in NF_i} T_j},$$

where NF_i = set of activities that follow activity i

R13- COMPR (Complex Ratio)

This rule is the ratio between time of immediate sons to resources of immediate sons and activity resources to activity time. The mathematical formula is,

$$\frac{\sum_{j \in NF_i} T_j \;/\; \sum_{k=1}^{M} \sum_{j \in NF_i} R_{ik}}{\sum_{k=1}^{M} R_{ik} \;/\; T_i}.$$

R14- RCOMPR (Reverse Complex Ratio)

This rule is the ratio between of activity time to activity time and activity resources to time of all sons and resources of all sons. The mathematical formula is expressed as,

$$\frac{\sum_{k=1}^{M} R_{ik} \;/\; T_i}{\sum_{j \in NF_i} T_j \;/\; \sum_{k=1}^{M} \sum_{j \in NF_i} R_{ik}}.$$

R15- Rule 15

This rule is the ratio between activity resources to activity time and time of immediate sons to resources of immediate sons. The mathematical formula is,

$$\frac{T_i + \sum_{k=1}^{M} R_{ik}}{\sum_{k=1}^{M} \sum_{k=1} R_{ik} + \sum_{j \in NF_i} T_j}.$$

R16- Rule 16

This rule is the ratio between resources of immediate sons to their times and activity resources to activity time. The mathematical formula is,

$$\frac{\sum_{k=1}^{M} \sum_{j \in NF_i} R_{ik} \;/\; \sum_{j \in NF_i} T_j}{\sum_{k=1}^{M} R_{ik} \;/\; T_i}.$$

R17- Rule 17

This rule is the ratio between activity resources and activity time and resources of immediate sons to time of immediate sons. The mathematical formula is:

$$\frac{\sum_{k=1}^{M} R_{ik} \;/\; T_i}{\sum_{k=1}^{M} \sum_{j \in NF_i} R_{ik} \;/\; \sum_{j \in NF_i} T_j}.$$

R18- MTOR

MTOR value of an activity is determined by the maximum sum of time over resources ratio that an activity controls through the network on any one path. *MTOR* can be presented mathematically as:

$$MTOR = \sum_{i=1}^{N} \sum_{j=1}^{L} \sum_{k=1}^{M} \frac{Tj}{R_{ijk}}.$$

R19- MWCA

This criterion is calculated at a specific weight for critical activities. (*HL*=2 for critical activities and *HL* =1 otherwise), to ensure that the critical activities will scheduled first *MWCA* value is calculated as the maximum sum of time over resources ratios that an activity controls through the network on any one path multiplied by *HL* as a weighted factor.

$$\text{MWCA} = \sum_{i=1}^{N} \sum_{j=1}^{L} \sum_{k=1}^{M} HL * \frac{Tj}{R_{ijk}}.$$

R20- MWROR

This criterion is calculated at a specific weight for the ratio of the resources required over the resources available (R_{ijk} / RA). *MWROR* value is determined as the maximum sum of time and resources multiplied by the ratio of the resources required over the resources available.

$$MWCA = \sum_{i=1}^{N} \sum_{j=1}^{L} \sum_{k=1}^{M} (R_{ijk} + Tj) * \frac{R_{ik}}{R_k}.$$

R 21- Rule 21

This criterion is calculated at a specific weight *W* (0<*W*<1). It is the sum of the weighted values of both normalized *MTOR* and *ACTIM* of the activity.

*R*21 = *W* (*MTOR*) + (1-*W*) (*ACTIM*)

R 22- Rule 22

This criterion is calculated at a specific weight *W* (0<*W*<1). It is the sum of the weighted values of both normalized *MTOR* and *ACTRES* of the activity.

*R*22 = *W* (*MTOR*) + (1-*W*) (*ACTRES*).

23- Rule 23

This criterion is calculated at a specific weight *W* (0<*W*<1). It is the sum of the weighted values of both normalized *MTOR* and *MACROS* of the activity.

*R*23 = *W* (*MTOR*) + (1-*W*) (*MACROS*).

R24- Rule 24

This criterion is calculated at a specific weight *W* (0<*W*<1). It is the sum of the weighted values of both normalized *MTOR* and *MROT* of the activity.

*R*24 = *W* (*MTOR*) + (1-*W*) (*MROT*)

R25- Rule 25

This criterion is calculated at a specific weight *W* (0<*W*<1). It is the sum of the weighted values of both normalized *MTOR* and *MWROR* of the activity.

*R*25 = *W* (MTOR) + (1-*W*) (*MWROR*)

R26- Rule 26

This criterion is calculated at a specific weight *W* (0≤ *W* ≤ 1) as the sum of the weighted values of both the normalized *SOTAMER* and *ACTIM* of activity

*R*26= *W* [*SOTAMER*] + (1-*W*) [*ACTIM*].

R27- Rule 27

This criterion is calculated at a specific weight *W* (0≤ *W* ≤ 1) as the sum of the weighted values of both the normalized *SOTAMER* and *MACTRES* of activity

*R*27= *W* [*SOTAMER*] + (1- *W*) [*MACTRES*].

R28- Rule 28

This criterion is calculated at a specific weight *W* (0≤ *W* ≤ 1) as the sum of the weighted values of both the normalized *SOTAMER* and *MACROS* of activity

*R*28= *W* [*SOTAMER*] + (*1*- *W*) [*MACROS*].

R29- Rule 29

This criterion is calculated at a specific weight *W* (0≤ *W* ≤ 1) as the sum of the weighted values of both the normalized *SOTAMER* and *MROT* of activity

*R*29= *W* [*SOTAMER*] + (1- *W*) [*MROT*].

R30- Rule 30

This criterion is calculated at a specific weight *W* (0≤ *W* ≤ 1) as the sum of the weighted values of both the normalized *SOTAMER* and *MTOR* of activity

*R*30= *W* [*SOTAMER*] + (1- *W*) [*MTOR*].

R31- Rule 31

This criterion is calculated at a specific weight *W* (0≤ *W* ≤ 1) as the sum of the weighted values of both the normalized *SOTAMER* and *MWROR* of activity

*R*31= *W* [*SOTAMER*] + (1- *W*) [*MWROR*].

R32- Rule 32

This criterion is calculated at a specific weight *W* (0≤ *W* ≤ 1) as the sum of the weighted values of both the normalized *TRTRR* and *RRTTR* of activity

*R*32= *W* [*TRTRR*] + (1- *W*) [*RRTTR*].

R33- Rule 33

This criterion is calculated at a specific weight W ($0 \leq W \leq 1$) as the sum of the weighted values of both the normalized *COMPR* and *RCOMPER* of activity

$R33 = W[COMPR] + (1- W)[RCOMPER]$.

R34- Rule 34

This criterion is calculated at a specific weight W ($0 \leq W \leq 1$) as the sum of the weighted values of both the normalized *SOTAMR* and *ICOMPER* of activity

$R34 = W[SOTAMR] + (1- W)[ICOMPER]$.

R35- Rule 35

This criterion is calculated at a specific weight W ($0 \leq W \leq 1$) as the sum of the weighted values of both the normalized *R/T^s /R/T^a and R/T^a / R/T^s* of activity

$R35 = W[R/T\hat{}s/R/T\hat{}a]+(1- W)[R/T\hat{}a/R/T\hat{}s]$.

R36- Rule 36

This criterion is calculated at a specific weight W ($0 \leq W \leq 1$) as the sum of the weighted values of both the normalized *SOTAMR* and *COMPER* of activity

$R36 = W[SOTAMR] + (1- W)[COMPER]$.

R37- Rule 37

This criterion is calculated at a specific weight W ($0 \leq W \leq 1$) as the sum of the weighted values of both the normalized *SOTAMR* and *RCOMPER* of activity

$R37 = W[SOTAMR] + (1- W)[RCOMPER]$.

R38- Rule 38

This criterion is calculated at a specific weight W ($0 \leq W \leq 1$) as the sum of the weighted values of both the normalized *SOTAMR* and *TRTRR* of activity

$R38 = W[SOTAMR] + (1- W)[TRTRR]$.

R39- Rule 39

This criterion is calculated at a specific weight W ($0 \leq W \leq 1$) as the sum of the weighted values of both the normalized *SOTAMR* and *RRTTR* of activity,

$R40 = W[SOTAMR] + (1- W)[RRTTR]$.

R40- Rule 40

This criterion is calculated at a specific weight W ($0 \leq W \leq 1$) as the sum of the weighted values of both the normalized *SOTAMR* and *R/T^s/ R/T^a* of activity

$R41 = W[SOTAMR] + (1- W)[R/T\hat{}s /R/T\hat{}a]$.

R41- Rule 41

This criterion is calculated at a specific weight W ($0 \leq W \leq 1$) as the sum of the weighted values of both the normalized *SOTAMR* and *R/T^a / R/T^s* of activity

$R41 = W[SOTAMR] + (1- W)[R/T\hat{}a / R/T\hat{}s]$.

R42- RQ

This rule considers the resources requirements needed by an activity (i) and is given by

$$\sum_{k=1}^{M} R_{ik} .$$

R43- Rule 43

This criterion is calculated at a specific weight W ($0 \leq W \leq 1$) as the sum of the weighted values of both the normalized *SOTAMR* and *RQ* of activity

$R43 = W[SOTAMR] + (1- W)[RQ]$

R44- ACTIM

This ACTIM value of activity is calculated as the maximum time that activity controls through the network on any one path,

$$ACTIM = \sum_{i=1}^{N} \sum_{j=1}^{L} T_{ij} .$$

R45- TTOS

The TTOS value of an activity is calculated as the time the activity controls through all sons of it,

$$TTOS = \sum_{j \in NF_i} T_j .$$

R46 - ATATTOS

The *ATATTOS* value of an activity is calculated as the sum of activity time and the total time that the activity controls through all sons of it,

$$ATATTOS = T_i + \sum_{j \in NF_i} T_j .$$

R47 – DBT

The DBT value of an activity is calculated as the difference between *ATATTOS* and total time of parents of activity,

$$DBT = (Ti + \sum_{j \in NF_i} T_j) - \sum_{J \in Pi} T_j.$$

Where *Pi* is a set of activity that precede activity *i*.

R48- ROSTASN

ROSTASN value of an activity is calculated as the ratio between *ATATTOS* and number of immediate sons

$$ROSTASN = (T_i + \sum_{j \in NF_i} T_i) / \sum_{j \in NF_i} T_j .$$

R49- Rule 49

This criterion is calculated at a specific weight *W* (0≤ *W* ≤ 1) as the sum of the weighted values of both the normalized *MTOR* and *ICOMPR* of activity

Rule 49= *W* (*MTOR*) + (1-*W*) (*ICOMPR*).

R50- Rule 50

This criterion is calculated at a specific weight *W* (0≤ *W* ≤ 1) as the sum of the weighted values of both the normalized *MTOR* and *COMPR* of activity

Rule 50 = *W* (*MTOR*) + (1-*W*) (*COMPR*)

R51- Rule 51

This criterion is calculated at a specific weight *W* (0≤ *W* ≤ 1) as the sum of the weighted values of both the normalized *MTOR* and *RCOMPR* of activity

Rule 51 = *W* (*MTOR*) + (1-*W*) (*RCOMPR*).

R52- Rule 52

This criterion is calculated at a specific weight *W* (0≤ *W* ≤ 1) as the sum of the weighted values of both the normalized *MTOR* and *TRTRR* of activity

Rule 52 = *W* (*MTOR*) + (1-*W*) (*TRTRR*).

R53- Rule 53

This criterion is calculated at a specific weight *W* (0≤ *W* ≤ 1) as the sum of the weighted values of both the normalized *MTOR* and *RRTTR* of activity,

Rule 53= *W* (*MTOR*) + (*1-W*) (*RRTTR*).

R54- Rule 54

This criterion is calculated at a specific weight *W* (0≤ *W* ≤ 1) as the sum of the weighted values of both the normalized *MTOR* and Rule16 of activity,

Rule 54 = *W* (*MTOR*) + (*1-W*) (*RULE* 16).

R55- Rule 55

This criterion is calculated at a specific weight *W* (0≤ *W* ≤ 1) as the sum of the weighted values of both the normalized MTOR and Rule17 of activity,

Rule 55 = *W* (*MTOR*) + (1-*W*) (*RULE* 17).

As it is obvious from the above rules that all of them are designed or adapted to be applicable for scheduling both single resource constrained problem or multiple constrained problems *RCPSP*, *MRCPSP*. In case of the proposed rule is a ratio of a zero value of a numerator or dominator an index should be added. This index has a value equal to the order of the considered activity ascending for a zero value of dominator. This index will be either zero for non-critical activities or the least priority value calculated by the same rule for the preceding activities. The proposed scheduling schemes are grouped in an algorithm in order to evaluate the priorities for each activity belong to the project under scheduling process for either a single resource or multiple resource consideration and for any required scheduling scheme. The main objective to this coded algorithm in addition to evaluate the activity's priorities is to find the best schedule for the project under consideration using these variability's of scheduling schemes. Fig. 1 exhibits the conceptual flow chart of the proposed algorithm.

2. Test problem

The above heuristic rules are applied on 50 data set projects. Most of these projects have been used as investigated projects in references [1,3,11,13,23,30-32,39,43,74-79]. The number of activities of these test problems ranges from 10 to 65, the length of the calculated critical path of these projects ranges from 10 units of time to 121 units of time, the number of nodes from 7 to 40 nodes, maximum number of critical paths exists in project is three critical paths and the degree of complexity measure suggested by Shouman et al. [79] for these data set ranges from 8.13 to 98.46 complexity index value. The experiments have been done considering only single orientor critical resource (R1) for scheduling process then the experiments repeated for only single orientor critical resource R2 as main parameter for scheduling process and finally the scheduling process is directed for multiple critical resources R1 and R2 as dual required resources for each project of the data set. The max resource(s) required by any activity included in the project is (are) considered as the availability limit(s) through which the scheduling processes are obtained by the proposed algorithm. The tiebreakers are held unchanged for all scheduling processes for all the projects under all heuristic schemes.

3. Results

The above algorithm has been applied on the data set projects under consideration using the fifty-five scheduling schemes in both single and multiple resource consideration. The schedule for each project under each scheme has been obtained and the best schedule is obtained for each project for each case. Table 1 lists the best schedule for each project resource one oriented. The minimum deviation from the estimated completion time is presented and its percentage. The average percentage for this category is 57.642. Table 2 lists the best schedule for each project resource two oriented. The minimum deviation from the estimated completion time is presented and its percentage. The average percentage for this category is 98.316. Table 3 lists the best schedule for each project resource one and resource two oriented. The minimum deviation from the estimated completion time is presented and its percentage. The average percentage for this category is 100.75. Table 4 presents how much each rule achieved the best schedule for each category the their summation and percentage. Figs. 1 to 3 present how much each rule achieved the best schedule for each category respectively.

4. Conclusions

Some new scheduling schemes are proposed and others are adapted for multiple resources constrained scheduling process. The performance of these scheduling schemes are evaluated and appeared promising tendencies in scheduling process for single and multiple oriented critical resources(s). R53, RQ, R43, and R26 have achieved the best performance allover the categories under consideration. R43, and ACTIM have achieved the best performance for first category while R52, R53, RQ, MWCA, MTG2, MROT-MACTRES, and MACROS have achieved the best performance for second category. MWROR, MTOR, R25, R31, R41, R49, R52, R53, and R55 have achieved the best performance for third category. The proposed scheduling schemes are integrated in a coded algorithm not only for the evaluation process of the priority orders of the project activities under consideration for n oriented critical resources but also for determining the best schedule for the project under consideration using the available variability of scheduling schemes.

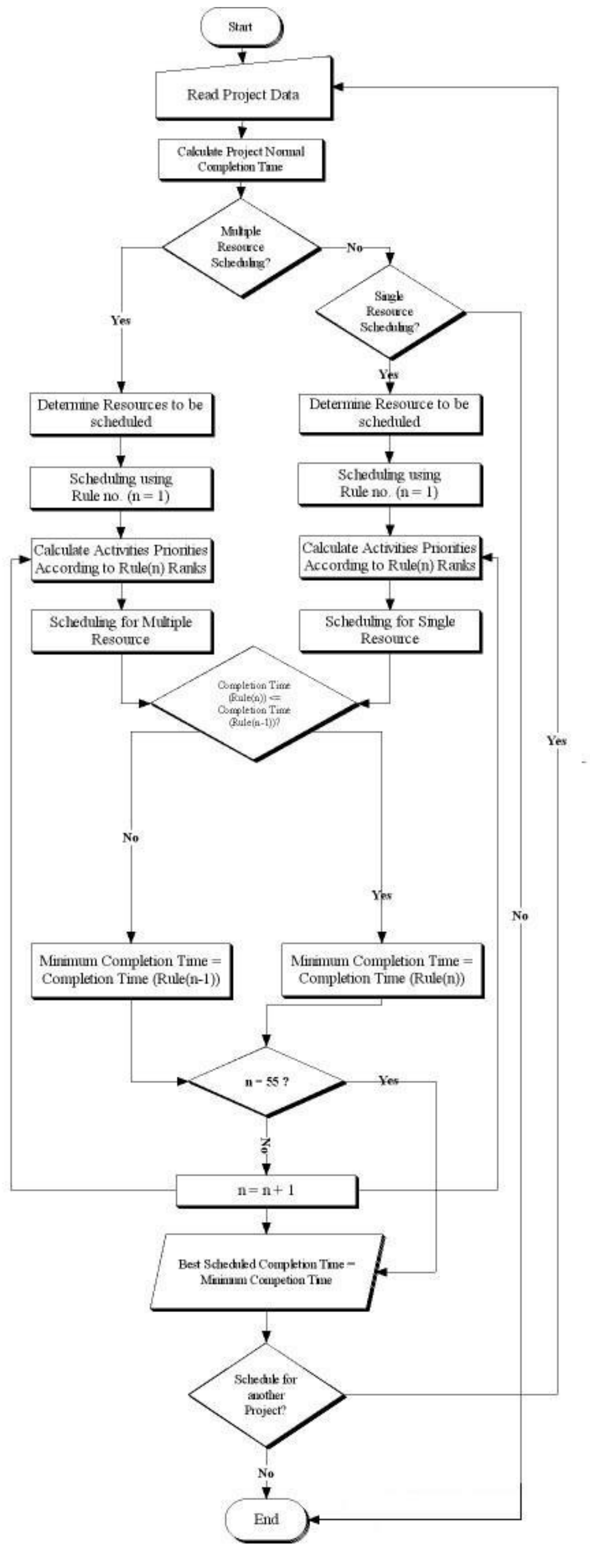

Fig. 1. conceptual flow chart of the proposed algorithm.

Table 1
The best schedule and minimum deviation for first category

No.	CP time	Minimum	Dev.	Percentage	No.	CP time	Minimum	Dev.	Percentage
P1	10	12	2	20	26	23	56	33	143.5
P2	24	35	11	45.8	27	13	28	15	115.4
P3	36	42	6	16.7	28	25	43	18	72
P4	28	36	8	28.6	29	18	20	2	11.1
P5	18	22	4	22.2	30	20	32	12	60
P6	15	19	4	26.7	31	29	32	3	10.3
P7	30	53	23	76.7	32	36	49	13	36.1
P8	8	13	5	62.5	33	52	117	65	125
P9	41	68	27	65.9	34	57	150	93	163.2
P10	29	31	2	6.9	35	120	208	88	73.3
P11	21	37	16	76.2	36	44	65	21	47.7
P12	113	211	98	86.7	37	23	100	50	100
P13	16	18	2	12.5	38	13	33	17	106.3
P14	52	89	37	71.2	39	25	114	22	23.9
P15	43	63	20	46.5	40	18	35	8	29.6
P16	61	66	5	8.2	41	20	169	89	111.3
P17	31	45	14	45.2	42	29	129	79	158
P18	35	40	5	14.3	43	36	102	36	54.5
P19	29	42	13	44.8	44	52	31	16	106.7
P20	35	53	18	51.4	45	57	33	12	57.1
P21	91	147	56	61.5	46	120	41	17	70.8
P22	63	80	17	27	47	44	48	20	71.4
P23	63	80	17	27	48	23	49	8	19.5
P24	121	165	44	36.4	49	13	40	4	11.1
P25	47	78	31	66	50	25	74	27	57.4

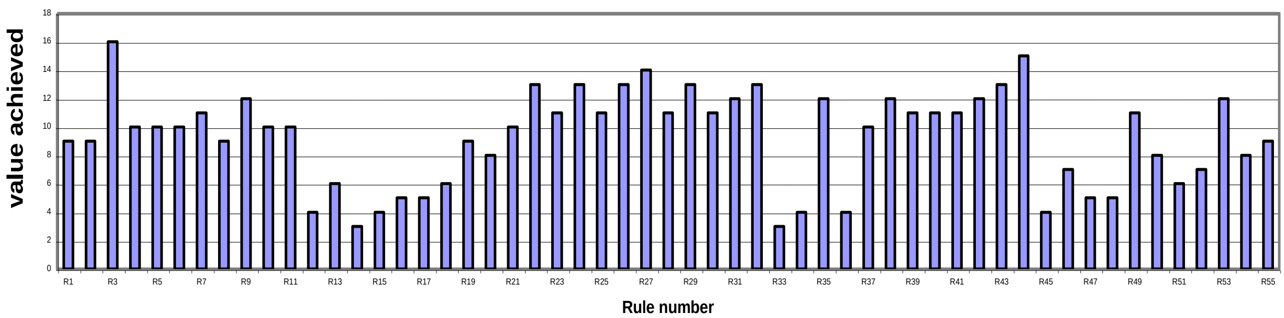

Fig. 2. Best schedule achieved for first category.

Table 2
The best schedule and minimum deviation for second category

No.	CP time	Minimum	Dev.	Percentage	No.	CP time	Minimum	Dev.	Percentage
P1	10	19	9	90	P26	23	47	24	104.3
P2	24	40	16	66.7	P27	13	32	19	146.2
P3	36	69	33	91.7	P28	25	46	21	84
P4	28	34	6	21.4	P29	18	30	12	66.7
P5	18	25	7	38.9	P30	20	31	11	55
P6	15	27	12	80	P31	29	62	33	113.8
P7	30	78	48	160	P32	36	74	38	105.6
P8	8	18	10	125	P33	52	126	74	142.3
P9	41	71	30	73.2	P34	57	153	96	168.4
P10	29	47	18	62.1	P35	120	208	88	73.3
P11	21	38	17	81	P36	44	60	16	36.4
P12	103	234	131	127.2	P37	50	130	80	160
P13	16	25	9	56.3	P38	16	40	24	150
P14	52	126	74	142.3	P39	92	206	114	123.9
P15	43	81	38	88.4	P40	27	60	33	122.2
P16	61	100	39	63.9	P41	80	228	148	185
P17	31	61	30	96.8	P42	50	107	57	114
P18	35	47	12	34.3	P43	66	93	27	40.9
P19	29	50	21	72.4	P44	15	35	20	133.3
P20	35	87	52	148.6	P45	21	32	11	52.4
P21	91	186	95	104.4	P46	24	60	36	150
P22	63	91	28	44.4	P47	28	64	36	128.6
P23	63	119	56	88.9	P48	41	66	25	61
P24	121	222	101	83.5	P49	36	55	19	52.8
P25	48	142	94	195.8	P50	47	98	51	108.5

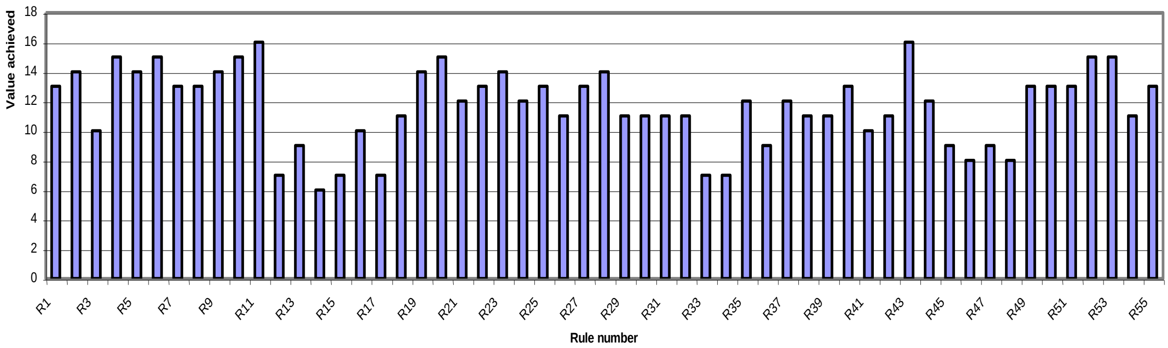

Fig. 3. Best schedule achived for second category.

Table 3
The best schedule and minimum deviation for third category

No.	CP time	Minimum	Dev.	Percentage	No.	CP time	Minimum	Dev.	Percentage
P1	10	12	2	20	P26	23	61	38	165.2
P2	24	35	11	45.8	P27	13	34	21	161.5
P3	36	69	33	91.7	P28	25	38	13	52
P4	28	36	8	28.6	P29	18	30	12	66.7
P5	18	25	7	38.9	P30	20	35	15	75
P6	15	19	4	26.7	P31	29	68	39	134.5
P7	30	53	23	76.7	P32	36	75	39	108.3
P8	8	13	5	62.5	P33	52	133	81	155.8
P9	41	68	27	65.9	P34	57	161	104	182.5
P10	29	31	2	6.9	P35	120	251	131	109.2
P11	21	40	19	90.5	P36	44	76	32	72.7
P12	103	267	164	159.2	P37	50	146	96	192
P13	16	26	10	62.5	P38	16	46	30	187.5
P14	52	126	74	142.3	P39	92	211	119	129.3
P15	43	86	43	100	P40	27	60	33	122.2
P16	61	66	5	8.2	P41	80	238	158	197.5
P17	31	64	33	106.5	P42	50	144	94	188
P18	35	50	15	42.9	P43	66	103	37	56.1
P19	29	59	30	103.4	P44	15	37	22	146.7
P20	35	86	51	145.7	P45	21	36	15	71.4
P21	91	203	112	123.1	P46	24	60	36	150
P22	63	94	31	49.2	P47	28	69	41	146.4
P23	63	119	56	88.9	P48	41	65	24	58.5
P24	121	213	92	76	P49	36	55	19	52.8
25	48	146	98	204.2	P50	47	89	42	89.4

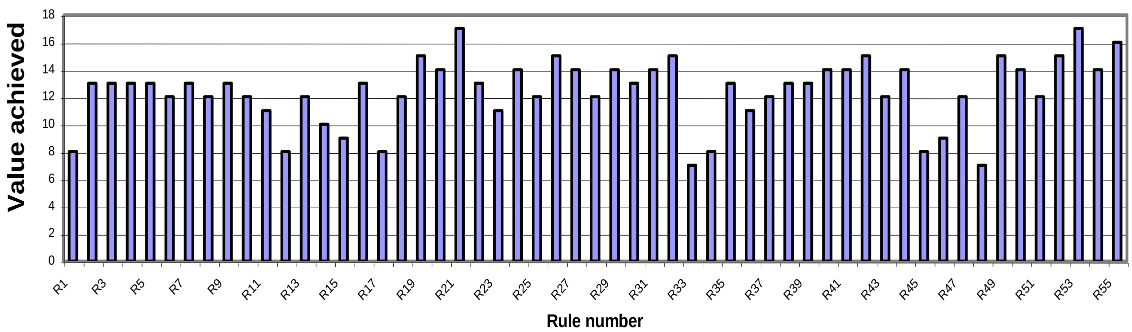

Fig. 4. Best schedule achieved foe third category.

Table 4
How much each rule achieved the best schedule for each category

Rule	R1	R2	MR	Sum	Percentage	Rule	R1	R2	MR	Sum	Percentage
MROT	9	13	8	30	20.0	RULE28	13	11	14	38	25.3
MACTRES	9	14	13	36	24.0	RULE29	11	11	13	35	23.3
ACTIM	16	10	13	39	26.0	RULE30	12	11	14	37	24.7
MTIMRES	10	15	13	38	25.3	RULE31	13	11	15	39	26.0
MGENRES	10	14	13	37	24.7	RULE32	3	7	7	17	11.3
MACROS	10	15	12	37	24.7	RULE33	4	7	8	19	12.7
SOTAMR	11	13	13	37	24.7	RULE34	12	12	13	37	24.7
MTMROS	9	13	12	34	22.7	RULE35	4	9	11	24	16.0
MROT-ACTIM	12	14	13	39	26.0	RULE36	10	12	12	34	22.7
MROT-MACTRES	10	15	12	37	24.7	RULE37	12	11	13	36	24.0
MTG2	10	16	11	37	24.7	RULE38	11	11	13	35	23.3
TRTTR	4	7	8	19	12.7	RULE39	11	13	14	38	25.3
RRTTR	6	9	12	27	18.0	RULE40	11	10	14	35	23.3
COMPR	3	6	10	19	12.7	RULE41	12	11	15	38	25.3
RCOMPR	4	7	9	20	13.3	RQ	13	16	12	41	27.3
ICOMPR	5	10	13	28	18.7	RULE43	15	12	14	41	27.3
RULE16	5	7	8	20	13.3	TTOS	4	9	8	21	14.0
RULE17	6	11	12	29	19.3	ATATTOS	7	8	9	24	16.0
MTOR	9	14	15	38	25.3	DBT	5	9	12	26	17.3
MWCA	8	15	14	37	24.7	ROSTASN	5	8	7	20	13.3
MWROR	10	12	17	39	26.0	R.49	11	13	15	39	26.0
RULE21	13	13	13	39	26.0	R.50	8	13	14	35	23.3
RULE22	11	14	11	36	24.0	R.51	6	13	12	31	20.7
RULE23	13	12	14	39	26.0	R.52	7	15	15	37	24.7
RULE24	11	13	12	36	24.0	R.53	12	15	17	44	29.3
RULE25	13	11	15	39	26.0	R.54	8	11	14	33	22.0
RULE26	14	13	14	41	27.3	R.55	9	13	16	38	25.3
RULE27	11	14	12	37	24.7						

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