# Smoothing influence of highest priority resource order on lower priority resource order in project scheduling

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Resource smoothing is considered as one of promising tools for single resource utilization in project scheduling. The specific resource smoothing problem addressed in the current work is in a constrained smoothing feature. Smoothing process is applied on highest priority resource order. The influence of smoothing process is studied on lower priority resource order. Some new measures are introduced as measuring performance criteria for smoothing feasibility. A set of 50 projects are under study consideration. General remarks and conclusions are presented.

هذا البحث يتناول اسلوب تنعيم الموارد كوسيلة لزيادة منفعة الموارد المستخدمة في جدولة المشروعات وكذا تأثير أسلوب تنعيم الموارد ذات الحرجية الأعلى على الموارد ذات الحرجية الأقل في المشروعات متعددة الموارد. في هذه الدراسة تم اقتراح أربعة معايير جديدة يتم من خلالها قياس مدى كفاءة أسلوب تنعيم الموارد بهدف زياده مدى المنفعة بالنسبة للموارد المستخدمة. تم تجربة الأسلوب المقترح على فئة تشمل خمسون مشروع وقد خلصت الدراسة إلى أن أسلوب التنعيم هو أسلوب جيد لزيادة مستوى المنفعة بالنسبة للموارد وكذا أسلوب جيد لجدولة المشروعات وذلك بالنسبة للمشروعات ذات المورد الواحد أو المشروعات ذات الموارد المتعددة وذات الدوال المتشابة السمات. أما في حالة اختلاف دوال توزيع الموارد فلابد من دراسة مدى جدوى استخدام أسلوب التنعيم لزيادة درجة منفعة الموارد من عدمه وحتى لا يتم استبدال درجات الحرجية بين الموارد نتيجة عملية التنعيم.

**Keywords:** Constrained smoothing, Resource allocation, Multiple resource problem, Performance evaluation criteria.

## 1. Introduction

Resource smoothing procedures uniform any fluctuations in resource profile and usage. The slack available on jobs is utilized for rescheduling process to give the most acceptable profile(s) of resource usage over time. The acceptable profile is judged according to some predetermined criteria such as maximum utilization of resources, and under the constraint that, the project duration is not allowed to increase [1]. For single resource scheduling problem, the smoothing process will be very active tool for increasing resource utility. The complexity will be multiplied for unconstrained multiple resource problems and highly elevated for constrained one. This is due to the highest criticality order of that resource and maximum expected shortage will be for the highest resource order. As a matter of fact, smoothing process has a crucial influence on lower resource order and may affect the scheduling process itself. Effective solution procedures for resource utilization in project scheduling have been a goal of researchers over the last four decades. A multi-period resource allocation problem has been studied by Klein et al. [2]. The major issues addressed in that study is determining whether there are sufficient resources to sustain specified levels for various activities and if so, a feasible resource allocation scheme is found through maximal flow of related network. A multi-period minimax resource allocation model with substitutable resources has been introduced by Nguyen et al. [3]. The problem is solved by primal-dual algorithm that was efficiently implemented using a maximal flow algorithm. The primal dual algorithm is capable of handling large scale problem. A scheduling procedure for achieving minimum resource consumption of continuously, divisible, and doubly constrained resources has been introduced by Weglarz [4]. This procedure ensures minimum project duration for a given level of resource usage and the minimum level of resource usage ensures minimum project duration of a given level of resource consumption. A linear programming model has been advised for resource distribution in projects by Babu et al. [5]. In this model a continuous scale from zero to one is adopted to specify the quality obtained at each activity. The overall project quality is a function of the quality levels attained at the individual activities. A survey on both renewable and nonrenewable resource constrained scheduling problem is presented by Ozdamar et al. [6]. The problem is classified according to specified objectives and constraints. The complexity of solving these models by optimization techniques is noticed. Also, the well-known dispatching rules scheduling algorithms that consists of a decision making process utilizing the problem constraint as a base of selection are reported. A 0-1 linear programming model of the problem is presented by Mingozzi et al. [7]. In this model an exponential number of variables, corresponding to all feasible subsets of activities that can be simultaneously executed without violating resources constraints, is used. Different relaxations are used to drive new lower bounds. A tree search algorithm based on the above formulation that uses new lower bounds and dominance criteria is also presented. A branch and bound procedure is introduced by lcmeli et al. [8] to solve the resource scheduling problem with discounted cash flows. The procedure exploits the known fact that potential resource violations can be eliminated by introducing additional precedence relations between certain project activities. A procedure for limited resources availability has been presented by Simpson III et al. [9]. This procedure takes the advantage of emerging technology provided by multiple parallel processors to find and verify an optimal schedule for project under considerations of multiple resource' distributions. In this approach, multiple solutions trees are searched simultaneously in the guest for a minimum duration schedule. The resource utilization problem is discussed carefully as a tool for scheduling projects in case of constrained resource statement by Shouman et al. [10,11]. The main criteria of their studies are to maximize the resource usage or utility in scheduling project activities and reducing the project makespan. It is noticed from aforementioned literature review, the maximization of resources utilities is sought as a crucial target for all researchers. This crucial target is not violated in the current work, where it is directed to multiple resource problem considering smoothing resource technique as the tool used for resource utilization. In such cases, the resource skyline for second priority resource order is changed as a result of smoothing process of first priority order and the resource skyline function may be influenced in its order level. Also, a calendar orientation providing a convenient mean of checking the schedule concerning the utilization of key resources should be applied.

## 2. Resource distribution function

The capacity of resources required by each job is specified when its duration is calculated; then when the schedule standing times have been decided, the requirements are totaled to all concurrent jobs for each discrete time period. There may be either single resource (one type) or multiple resource (more than one type). Many resource profiles show much the same general shape, in that they build up quickly to a peak and then tail off gradually to zero [12]. In case of multiple resource types, the profile functions (RI,R2) may be in either decreasing in the most sub domain (XI) or increasing in the most sub domain (X2) towards the project completion. These functions are either in phase (XI or X2) or out of phase (X3) for their profiles. Fig. 1. shows the most popular and famous profile conditions, to which they may be fitted continues curves. The curve is envelope and is described by a mathematical equation called the profile function or Norden's function [12]. Other mathematical relationships such as beta and gamma functions, or the normal probability integral might turn out to be more appropriate for some rarely classes. In the current study, Norden's function is considered

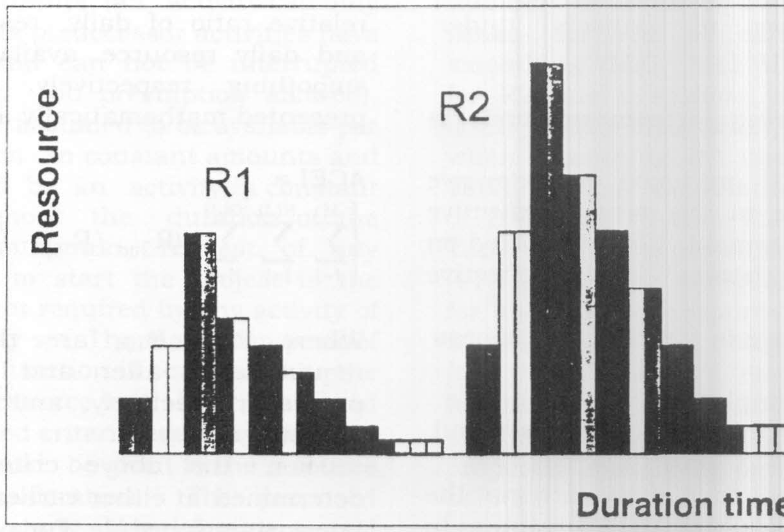


Fig. 1-a. Decreasing resource functions (X1).

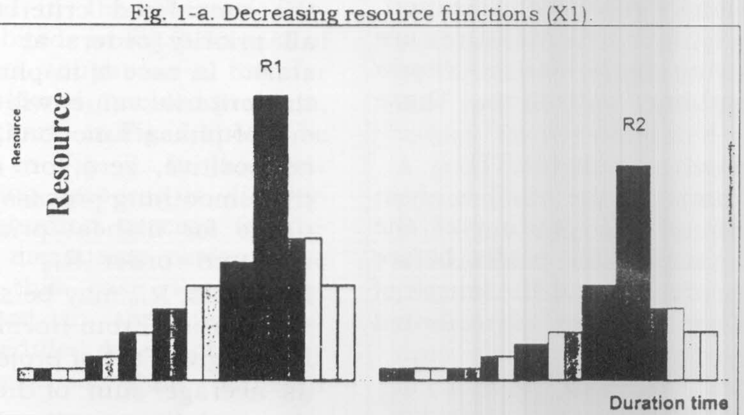


Fig. 1-b. Increasing resource functions (X2).

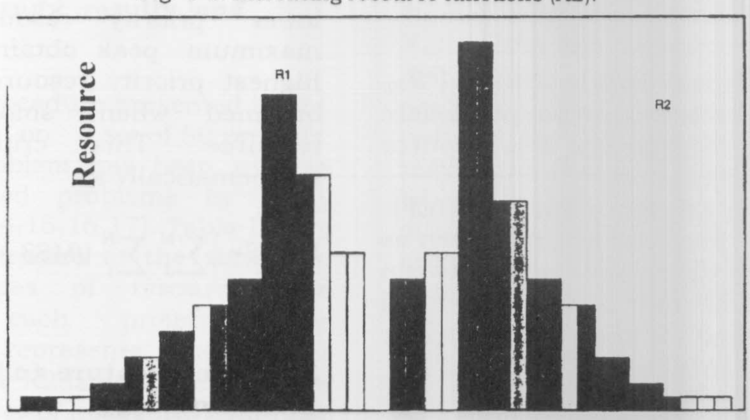


Fig. 1-c. Conflicting resource functions (X3).

for resource types of projects under consideration.

## 3. Proposed measuring performance criteria

Neely et al. [13] produced an extensive review of literature in the area of effective performance measurement. They reported on the following themes for effective measurements:

1- They should relate to a strategy business processes.
2- They should be simple and efficient.
3- They should be influenced by the user and support him.

It can be argued that these are not the only factors that contribute to effectiveness in performance measures for resource utilization. In the current study, four new measures are proposed as measuring performance criteria for resource smoothing utilization. These measures are:

1- Average Saved Resource Time (ASRT)

For a given set of projects, the ASRT is given as the average sum of the product of the difference between maximum peaks before and after smoothing process and the length of the critical path. This criterion is presented mathematically as:

$$ASRT = \left\{ \sum_{J=1}^{M} \sum_{I=1}^{N(J)} CP(R_{1ij} - R_{2ij}) \right\} / M . \quad (1)$$

Where cp is the critical path length, $R_{1ij}$, $R_{2ij}$, are maximum peaks of resource type I before and after smoothing respectively, N is resource type set, and M is projects set.

2-Average Smoothing Efficiency Factor (ASEF)

For a given set of projects, ASEF is given as the average sum of the relative ratio between saved resource time and actual smoothed resource time required for smoothing process. This criterion is presented mathematically as:

$$ASEF = \left\{ \sum_{J=1}^{M} \sum_{I=1}^{N(J)} CP(R_{1ij} - R_{2ij}) / R_{2ij} \right\} / M . \quad (2)$$

3-Average Criticality Efficiency Index (ACEI)

For a given set of projects, ACEI is given as the average sum of the difference between the relative ratio of daily resource requirements and daily resource available after and before smoothing respectively. This criterion is presented mathematically as:

$$ACEI = \left\{ \sum_{J=1}^{M} \sum_{I=1}^{N(J)} \sum_{d=1}^{D(J)} ((R_{2ijd} / R_{2ij}) - (R_{1ijd} / R_{1ij})) \right\} / M . \quad (3)$$

Where $R_{2ijd}$, $R_{1ijd}$ are the daily resource requirements after and before smoothing process respectively, and D (j) is the project duration in days.

For the above criteria, $R_{1ij}$ may be determined at either earliest start schedule or latest start schedule. For perfect evaluation of the considered criteria, $R_{1ij}$, must be held for all priority orders at either earliest or latest start. In case of in-phase resource functions, the criteria value will be positive, while for out-of-phase functions, the criteria value may be positive, zero, or negative. This is due to the smoothing process will unify the resource usage for highest priority order, i.e. for this resource order $R_{1ij} > R_{2ij}$, For dissimilar functions, $R_{1ij}$ may be $\leq R_{2ij}$.

4-Deviation From Normal Smoothing (DFNS)

For a given set of projects, the (DFNS) is given as average sum of the absolute percentage of the relative ratio for; the difference of maximum peak obtained when smoothing lower priority resource itself and the maximum peak obtained due to smoothing highest priority resource ; to that maximum obtained when smoothing lower priority resource. This criterion is presented mathematically as:

$$DFNS = \left\{ \sum_{J}^{M} \sum_{1}^{N} ((MS3 - MS2) / MS3) * 100 \right\} LM . \quad (4)$$

## 3. Problem feature and solution methodology

While a variety of scheduling objectives have been considered, the majority of the presented work has been focused on studying the effect of smoothing process on multi resource problem. It is assumed that an activity is subjected to technological precedence constraints (an activity can only be started if all its predecessor activities have been finished) and can not be interrupted once begun (no job preemption allowed). Resource set is assumed to be available per project completion in constant amounts and are also demand by an activity in constant amounts throughout the duration of the activity. The minimum request of any resource type I to start the project is the maximum amount required by any activity of the project activity set. The maximum peak of resource skyline function is considered as the unconstrained resource level. Priorities based on certain specified criteria ( cost, availability, weight, etc.) should be given to the resource set under consideration. The proposed procedure for study the aforementioned objective is described in the schematic flow chart which is exhibited in Fig.2. In case of smoothing process is sought as a tool for scheduling the considered tackled problem, the exhibited flow chart in Fig. 2 should be developed to be as in Fig. 3. In this flow chart, the scheduling process is directed basically on the evaluation process for the current suggested measuring performance criteria (MPC). In this case the project activities are started in their execution according to the scheduled dates obtained by the smoothing process that achieved maximum MPC.

## 4. Simulated case study ,results, and analysis

The proposed procedure presented in Fig. 2 has been applied on a set of 50 projects. This set of test problem has been used as standard investigated problems by many researchers [10,11,14,15,16,17]. Table 1. lists the main characteristics of the simulated projects. Two types of resources are considered for each project under consideration. RI represents the highest resource order while R2 is for lower resource priority order. Number of nodes (NN), number of activities (AN), project duration (PD), number of critical paths (PA), maximum peaks for RI at earliest , latest, and smoothing (MEI, MLI, MSI), maximum peaks for R2 due to earliest, latest, and smoothing of RI (ME2, ML2, MS2), and maximum peak when smoothing R2 itself (MS3) are listed in Table 1. Also the relation between functions of resources RI and R2 is exhibited in this Table (RBF). The developed Burgess algorithm [11] is used as a tool of, smoothing process for the highest resource order. A computer software has been designed and constructed for determining resource distribution functions, $R_{2ijd}$, $R_{1ijd}$ $R_{1ij}$, and $R_{2ij}$. All the maximum peaks at all circumstances and the proposed measuring performance criteria are pointed out by the aids of this software. The relation between the distribution functions is tabulated in this table. Table 2 lists the evaluated figures of the proposed measuring performance criteria in the current work. The last row in this table presents the average values for the evaluated performance criteria. A good visibility to the evaluated measuring performance criteria for the simulated test problems indicates an increase of resource utilization accompanied by smoothing process. This is because smoothing process unifies the rate of resource usage per unit time along with the project duration and the maximum peak of resource requested to schedule the project in its minimum due date is reduced. This remark is achievable for similar resource distribution functions (Xl or X2). When the resource set is of dissimilar distribution functions (X3), the maximum peak of highest resource priority order will be reduced by the smoothing process while the maximum peaks of lower priority orders may be increased more than the maximum available limits of these lower resource orders. In such cases, the resources priority orders may be changed where the highest resource order may be reduced in its highest order and vise is versa. However, this remark is easily seen by the aid of the proposed measuring performance criteria especially for projects (1, 6, 8, 14, 29, 30, 31, 32, 42 and 46).

Table 1 Main characteristics of simulated projects.

| J | NN | AN | PD | PA | ME1 | ML1 | MS1 | ME2 | ML2 | MS2 | MS3 | RBF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7 | 10 | 10 | 1 | 8 | 9 | 5 | 16 | 16 | 19 | 16 | X3 |
| 2 | 8 | 13 | 24 | 2 | 12 | 18 | 9 | 17 | 18 | 12 | 12 | X1 |
| 3 | 8 | 13 | 36 | 1 | 24 | 19 | 12 | 15 | 17 | 15 | 15 | X1 |
| 4 | 9 | 12 | 30 | 1 | 15 | 20 | 12 | 8 | 8 | 8 | 8 | X1 |
| 5 | 9 | 11 | 18 | 1 | 9 | 16 | 7 | 13 | 9 | 12 | 9 | X1 |
| 6 | 9 | 11 | 15 | 1 | 23 | 20 | 16 | 13 | 13 | 16 | 13 | X3 |
| 7 | 9 | 15 | 30 | 2 | 30 | 32 | 20 | 20 | 20 | 15 | 13 | X1 |
| 8 | 9 | 11 | 10 | 1 | 16 | 17 | 12 | 21 | 24 | 25 | 17 | X3 |
| 9 | 10 | 12 | 41 | 1 | 13 | 20 | 13 | 10 | 11 | 10 | 10 | X2 |
| 10 | 10 | 15 | 29 | 1 | 7 | 18 | 6 | 67 | 47 | 47 | 41 | X1 |
| 11 | 11 | 13 | 21 | 1 | 22 | 21 | 15 | 60 | 64 | 49 | 47 | X1 |
| 12 | 11 | 15 | 100 | 2 | 27 | 27 | 21 | 49 | 49 | 48 | 48 | X1 |
| 13 | 12 | 15 | 16 | 1 | 14 | 17 | 9 | 43 | 40 | 40 | 30 | X1 |
| 14 | 15 | 18 | 52 | 1 | 19 | 21 | 14 | 45 | 51 | 55 | 45 | X3 |
| 15 | 16 | 24 | 39 | 1 | 16 | 16 | 9 | 45 | 41 | 39 | 39 | X1 |
| 16 | 17 | 21 | 16 | 1 | 18 | 20 | 11 | 41 | 29 | 25 | 25 | X1 |
| 17 | 17 | 22 | 32 | 1 | 14 | 16 | 8 | 32 | 30 | 23 | 23 | X1 |
| 18 | 19 | 24 | 35 | 1 | 11 | 18 | 11 | 21 | 22 | 23 | 22 | X1 |
| 19 | 20 | 28 | 29 | 2 | 26 | 31 | 15 | 25 | 44 | 24 | 19 | X1 |
| 20 | 24 | 31 | 35 | 2 | 32 | 23 | 14 | 38 | 30 | 29 | 25 | X1 |
| 21 | 23 | 41 | 91 | 2 | 40 | 32 | 30 | 84 | 85 | 84 | 66 | X1 |
| 22 | 24 | 30 | 63 | 1 | 16 | 20 | 10 | 39 | 34 | 29 | 25 | X1 |
| 23 | 28 | 38 | 63 | 1 | 28 | 28 | 17 | 61 | 65 | 57 | 50 | X1 |
| 24 | 32 | 43 | 124 | 1 | 12 | 13 | 11 | 18 | 20 | 17 | 17 | X1 |
| 25 | 40 | 54 | 47 | 1 | 41 | 37 | 17 | 98 | 76 | 47 | 47 | X1 |
| 26 | 10 | 18 | 23 | 1 | 16 | 17 | 13 | 30 | 30 | 28 | 28 | X2 |
| 27 | 8 | 10 | 13 | 1 | 11 | 16 | 11 | 21 | 21 | 21 | 21 | X2 |
| 28 | 10 | 13 | 25 | 2 | 14 | 17 | 11 | 42 | 30 | 31 | 30 | X1 |
| 29 | 10 | 12 | 18 | 2 | 10 | 20 | 9 | 24 | 27 | 34 | 21 | X3 |
| 30 | 8 | 12 | 20 | 2 | 10 | 15 | 9 | 31 | 33 | 35 | 25 | X3 |
| 31 | 17 | 18 | 29 | 1 | 10 | 15 | 9 | 30 | 34 | 37 | 29 | X3 |
| 32 | 15 | 18 | 34 | 1 | 32 | 21 | 19 | 43 | 58 | 65 | 40 | X3 |
| 33 | 25 | 37 | 52 | 1 | 61 | 64 | 30 | 88 | 93 | 57 | 51 | X1 |
| 34 | 24 | 32 | 57 | 1 | 60 | 59 | 29 | 119 | 119 | 77 | 29 | X1 |
| 35 | 36 | 42 | 120 | 1 | 54 | 46 | 39 | 48 | 32 | 27 | 24 | X1 |
| 36 | 18 | 28 | 44 | 2 | 32 | 32 | 26 | 84 | 79 | 70 | 70 | X1 |
| 37 | 23 | 34 | 50 | 1 | 38 | 32 | 18 | 32 | 33 | 23 | 17 | X1 |
| 38 | 16 | 23 | 16 | 1 | 41 | 41 | 22 | 33 | 34 | 24 | 23 | X1 |
| 39 | 37 | 65 | 92 | 1 | 73 | 67 | 20 | 51 | 58 | 31 | 22 | X1 |
| 40 | 16 | 24 | 27 | 2 | 32 | 20 | 16 | 35 | 32 | 33 | 23 | X2 |
| 41 | 26 | 36 | 80 | 3 | 37 | 34 | 27 | 56 | 47 | 53 | 41 | X1 |
| 42 | 30 | 46 | 50 | 3 | 35 | 33 | 26 | 28 | 37 | 27 | 25 | X1 |
| 43 | 22 | 30 | 66 | 1 | 26 | 27 | 14 | 13 | 15 | 19 | 11 | X3 |
| 44 | 11 | 13 | 15 | 2 | 12 | 19 | 11 | 41 | 35 | 41 | 35 | X1 |
| 45 | 8 | 11 | 21 | 1 | 12 | 16 | 8 | 36 | 36 | 22 | 22 | X1 |
| 46 | 10 | 12 | 24 | 2 | 9 | 17 | 9 | 23 | 26 | 30 | 22 | X3 |
| 47 | 15 | 18 | 28 | 1 | 17 | 17 | 11 | 40 | 54 | 37 | 36 | X1 |
| 48 | 18 | 24 | 41 | 1 | 10 | 17 | 7 | 40 | 36 | 40 | 28 | X1 |
| 49 | 13 | 17 | 36 | 1 | 9 | 10 | 8 | 41 | 51 | 39 | 30 | X2 |
| 50 | 22 | 31 | 47 | 1 | 16 | 17 | 10 | 49 | 57 | 40 | 28 | X1 |

Table 2 Evaluated measuring performance criteria.

| J | $ASRT_J$ | | | | $ASEF_J$ | | | | $ACEI_J$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R1 | | R2 | | R1 | | R2 | | R1 | | R2 | | DFNS |
| | E | L | E | L | E | L | E | L | E | L | E | L | |
| 1 | 30 | 40 | -30 | -30 | .6 | 0.8 | .187 | -.187 | 3.925 | 4.35 | -.362 | -.987 | 18.75 |
| 2 | 12 | 36 | 20 | 24 | .33 | 1 | .416 | .333 | 4.027 | 7.277 | 4.632 | 5.361 | 0 |
| 3 | 432 | 252 | 0 | 72 | 1 | .583 | 0 | .133 | 13.29 | 9.639 | 2.333 | 4.247 | 0 |
| 4 | 90 | 240 | 0 | 0 | .25 | .66 | 0 | 0 | 2.393 | 4.86 | -.375 | -.125 | 0 |
| 5 | 36 | 162 | 18 | -54 | .285 | 1.28 | .083 | -.25 | 1.333 | 2.062 | .762 | -3.30 | 33.3 |
| 6 | 105 | 60 | -45 | -45 | .437 | .25 | -.187 | -.187 | 3.179 | 1.975 | -1.45 | -1.45 | 23.1 |
| 7 | 300 | 420 | 150 | 150 | .5 | .6 | .333 | .333 | 6.233 | 7.45 | 5.45 | 5.45 | 15.38 |
| 8 | 40 | 50 | -40 | -10 | .33 | .416 | -.16 | -.04 | 1.312 | 2.235 | -1.16 | -.025 | 47.1 |
| 9 | 0 | 287 | 0 | 41 | 0 | .538 | 0 | .1 | 0 | 3.965 | 0 | 2.736 | 0 |
| 10 | 29 | 348 | 580 | 0 | .166 | 2 | .425 | 0 | 2.857 | 10.55 | 6.602 | 0 | 14.63 |
| 11 | 147 | 126 | 231 | 315 | .466 | .4 | .224 | .306 | 4.557 | 3.663 | 3.382 | 3.694 | 4.25 |
| 12 | 600 | 600 | 100 | 100 | .285 | .285 | .02 | .02 | 15.01 | 16.30 | 2.144 | -0.03 | 0 |
| 13 | 80 | 128 | 48 | 0 | .555 | .888 | .075 | 0 | 3.745 | 4.417 | .53 | -0.5 | 33.33 |
| 14 | 260 | 364 | -520 | -208 | .357 | .5 | -.181 | -.072 | 7.789 | 10.62 | -4.52 | -.75 | 22.22 |
| 15 | 273 | 273 | 234 | 78 | .777 | .777 | .153 | .051 | 14.76 | 12.88 | 5.254 | 9.054 | 0 |
| 16 | 112 | 144 | 256 | 64 | .636 | .818 | .64 | .16 | 15.80 | 15.36 | 6.772 | 1.135 | 0 |
| 17 | 192 | 156 | 288 | 224 | .75 | 1 | .391 | .304 | 7:964 | 6.875 | 2.569 | 3.746 | 0 |
| 18 | 0 | 245 | 0 | -35 | 0 | .636 | 0 | -.043 | 0.545 | 7.595 | 1.782 | 1.087 | 4.5 |
| 19 | 319 | 464 | 29 | 580 | .733 | 1.06 | .041 | .833 | 6.669 | 10.04 | 1.355 | 7.92 | 26.31 |
| 20 | 630 | 315 | 315 | 35 | 1.28 | .642 | .31 | .034 | 11.05 | 6.254 | 6.648 | -.731 | 16 |
| 21 | 910 | 182 | 0 | 91 | .33 | .066 | 0 | .011 | 15.84 | 9.216 | 2.857 | 1.321 | 27.27 |
| 22 | 378 | 630 | 630 | 315 | .6 | 1 | .344 | .172 | 14.61 | 19.3 | 2.998 | 1.822 | 16 |
| 23 | 693 | 693 | 252 | 504 | .647 | .647 | .07 | .140 | 17.39 | 17.76 | .381 | 3.362 | 14 |
| 24 | 124 | 248 | 124 | 372 | .09 | .181 | .058 | .176 | 10.16 | 39.07 | -1.88 | 12.95 | 0 |
| 25 | 1128 | 940 | 2397 | 1363 | 1.41 | 1.17 | 1.05 | .617 | 21.68 | 20.89 | 15.27 | 11.99 | 0 |
| 26 | 69-- | 92 | 46 | 46 | .23 | .307 | .071 | .071 | 1.586 | 2.284 | 4.287 | 1.787 | 0 |
| 27 | 0 | 65 | 0 | 0 | 0 | .454 | 0 | 0 | 0 | 1.641 | .0475 | 0 | 0 |
| 28 | 75 | 150 | 275 | -25 | .272 | .545 | .354 | -.032 | 3.837 | 3.85 | 5.343 | -.337 | 3.33 |
| 29 | 18 | 198 | -180 | -126 | .11 | 1.22 | -.294 | -.205 | 1.033 | 5.183 | -2.37 | -1.48 | 61.9 |
| 30 | 20 | 120 | -80 | -40 | .11 | .666 | -.114 | -.057 | 1.311 | 4.844 | -1.08 | 1.277 | 40 |
| 31 | 29 | 174 | -203 | -87 | .11 | .666 | -.189 | -.081 | 2.171 | 9.835 | .54 | -1.30 | 27.58 |
| 32 | 442 | 68 | -748 | -238 | .684 | .105 | -.338 | -.107 | 8.26 | 1.754 | -9.42 | -.44 | 62.5 |
| 33 | 1612 | 1768 | 1612 | 1872 | 1.03 | 1.13 | .543 | .631 | 8.69 | 10.85 | 12.19 | 11.10 | 11.76 |
| 34 | 1767 | 1710 | 2964 | 2964 | 1.07 | 1.03 | .675 | .675 | 24.89 | 23.94 | 13.91 | 13.14 | 165.5 |
| 35 | 1800 | 840 | 2520 | 600 | .384 | .179 | .777 | .185 | 24.38 | 20.23 | 18.73 | 10.43 | 12.52 |
| 36 | 264 | 264 | 616 | 396 | .23 | .230 | .2 | .128 | 4.625 | 4.594 | 3.657 | 2.876 | 0 |
| 37 | 1000 | 700 | 450 | 500 | 1.11 | .777 | .391 | .434 | 20.09 | 16.20 | 7.343 | 7.939 | 35.29 |
| 38 | 304 | 304 | 144 | 160 | .863 | .863 | .375 | .416 | 6.477 | 6.55 | 3.143 | 3.298 | 4.35 |
| 39 | 4876 | 4324 | 1840 | 2484 | 2.65 | 2.35 | .645 | .870 | 13.45 | 11.48 | 8.453 | 6.493 | 40.91 |
| 40 | 432 | 108 | 54 | -27 | 1 | .25 | .06 | -.03 | 8.531 | 3.712 | .458 | -.172 | 43.48 |
| 41 | 800 | 560 | 240 | -480 | .37 | .259 | .056 | -.113 | 13.82 | 9.654 | .839 | 3.597 | 29.27 |
| 42 | 450 | 350 | 50 | 500 | .346 | .269 | .037 | .370 | 8.285 | 5.393 | -1.36 | 7.512 | 8 |
| 43 | 594 | 660 | -396 | -264 | .529 | .588 | -.315 | -.210 | 14.34 | 14.54 | -10.5 | -6.8 | 72.72 |
| 44 | 15 | 120 | 0 | -90 | .09 | .727 | 0 | .146 | 1.37 | 4.822 | -.025 | -1.79 | 17.14 |
| 45 | 84 | 168 | 294 | 294 | .5 | 1 | .636 | .636 | 5 | 7.625 | 6.819 | 6.819 | 0 |
| 46 | 0 | 192 | -168 | -96 | 0 | .888 | -.233 | -.133 | 0 | 0 | -2.26 | -3.06 | 36.36 |
| 47 | 168 | 168 | 84 | 476 | .545 | .545 | .081 | .459 | 6.588 | 6.706 | 1.428 | 7.229 | 2.77 |
| 48 | 123 | 410 | 0 | -164 | .428 | 1.42 | 0 | -.1 | 9.128 | 17.25 | -.175 | -1.17 | 42.86 |
| 49 | 36 | 72 | 72 | 432 | .125 | .25 | .051 | .307 | 2.152 | 4.475 | 2.804 | 5.784 | 30 |
| 50 | 282 | 329 | 393 | 799 | .6 | .7 | .225 | .425 | 12.15 | 12.66 | 7.127 | 9.463 | 42.86 |
| Ave. | 443.6 | 428.3 | 298.3 | 276.6 | .524 | .712 | .159 | .1526 | 8.167 | 9.297 | 2.682 | 2.858 | 22.11 |

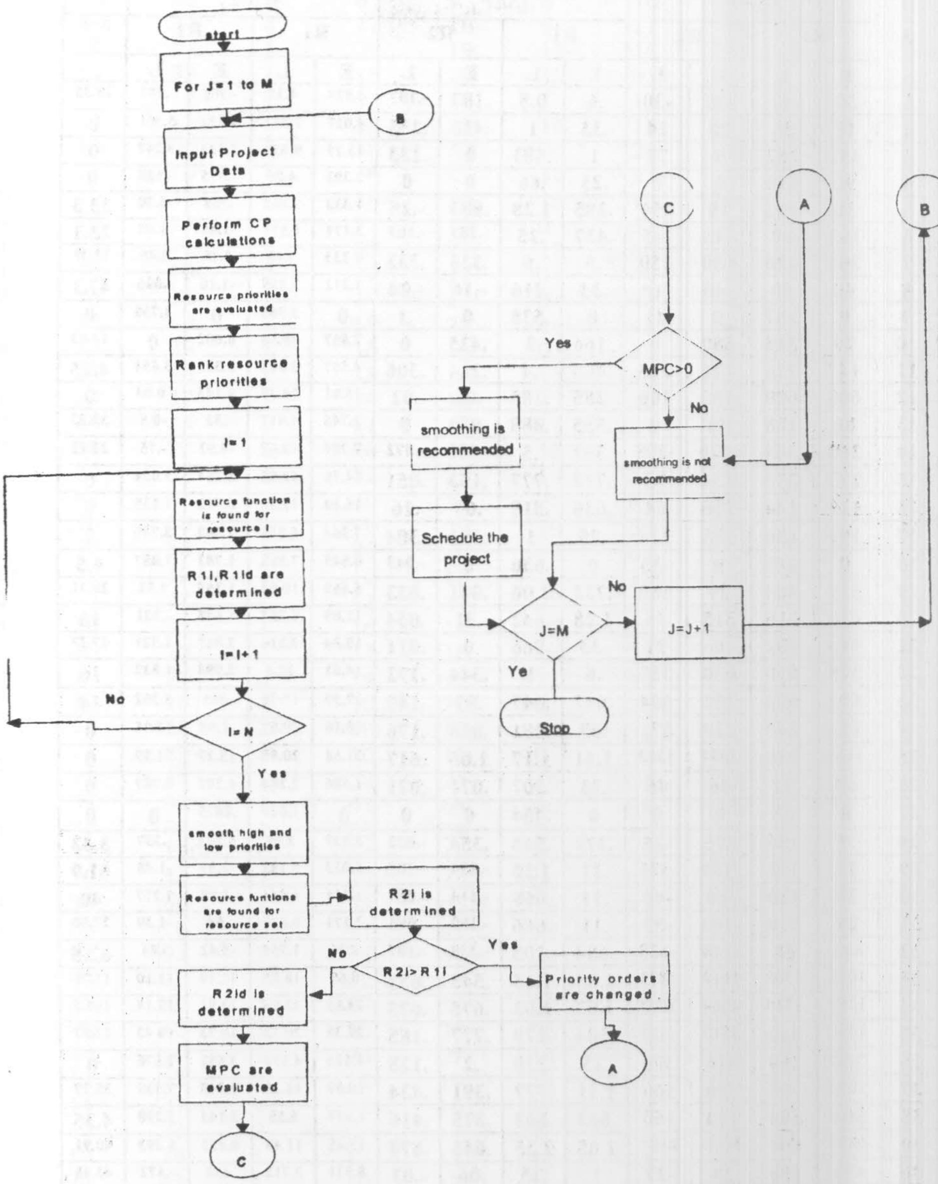


Fig. 2. Flow chart for proposed solution procedure.

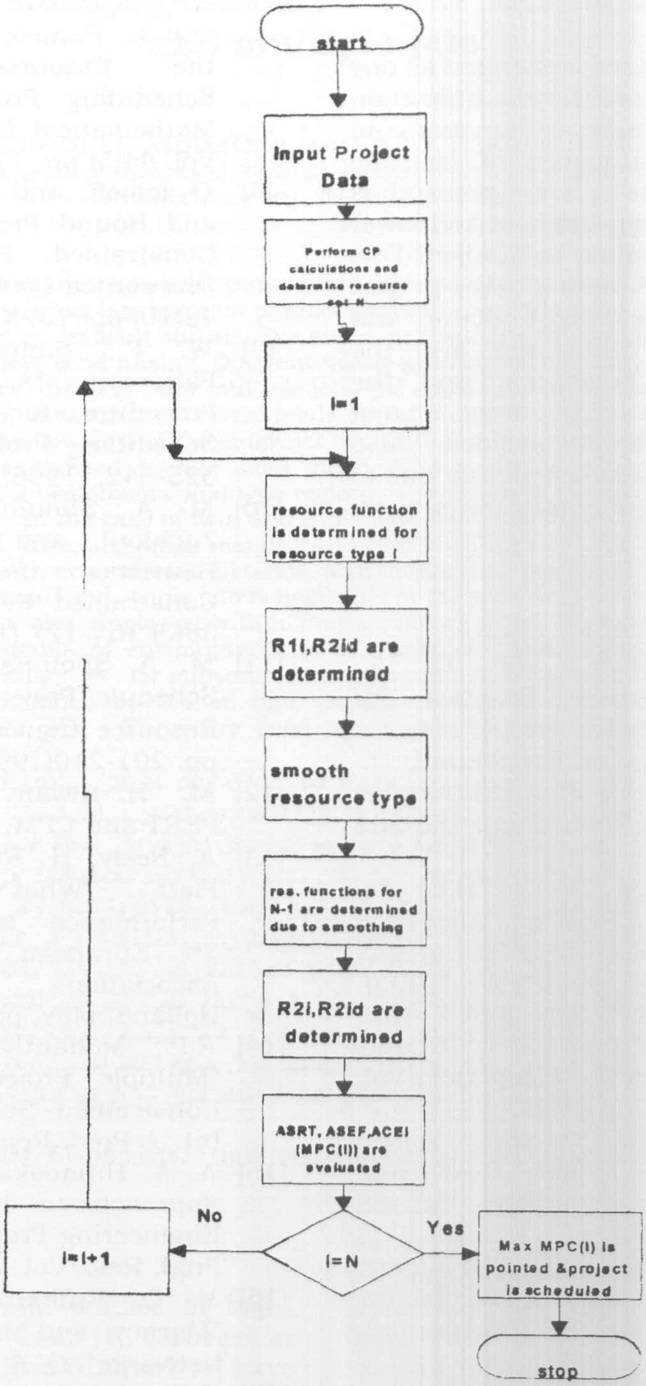


Fig. 3. Flow for scheduling projects based on smoothing.

## 5. Conclusion

Smoothing process is recommended as one of vital and promising tools for the utilization of in-phase multiple resource functions in project scheduling. As a matter of fact, the main contribution of the current research is that, the relation between highest and lower priority profile functions must be studied. This study is crucial because, it directs the project manager to his or her right action and decision for the best utilization over the available domain of resources, and the changeover of the criticality order among resource functions will be avoided. Also smoothing process improves scheduling due to the reduction of resource maximum peak accompanied by smoothing.

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