A NEW APPROACH TO SCHEDULE PROJECTS OF SINGLE CONSTRAINED RESOURCE CONSIDERATION

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ABSTRACT

In projects under constrained resource consideration, there is a vital objective to schedule each activity so that; project completion dates are met or their over-runs are minimized, idle resources are minimized, and resource requirements do not exceed stated availability. In this article, the excess resources under the available limit are utilized in the compression of some project activities such that the resource bound is not exceeded. ROT,ACTIM,ACTRES, and GENERS are used for scheduling six different projects each at two different resource levels before and after utilization. The reported results show that an increase of the utilization for the available resources has been achieved and the rendered schedules are the best for all the considered rules, projects, and resource levels.

Keywords: Scheduling, Resource allocation, Project management.

INTRODUCTION AND LITERATURE REVIEW

Project management is less difficult if procedure relationships constrain the activity schedule. PERT and CPM techniques, ridley provide allowable time windows for scheduling the activities. The objective is to complete the project by the minimal possible time permitted by the precedence relationships. Also, activities do not get completed on their own; rather, they consume resources. The scheduling problem becomes difficult to solve when the required resources are available in limited amounts, because the issue of allocating scarce resources among completing, activities must be considered in optimizing a specific objective. This problem is known as resource-constrained project scheduling problem and does not present on isolated area of research. Eight priority rules for ranking activities of project under limited resources are proposed by Khattab and Choobin [8]. The capabilities of these rules are compared using five measures of performance by complying the set of networks used by Elsayed and Naser [4]. An interactive project management approach based on Perti-net to overcome the limitations of network diagrams has been presented by Jongwook et al [6]. In this approach, the project manager does fine tuning of planning and scheduling with the resource constraints embedded in the plane representation.The proposed structure is applicable to the control of more general discrete event dynamic systems as well as the project management problem.A study deals with resource assignment modeling approach into a multi-project management context has been presented by Opal et al [11].The approach divides the resource assignment complexity into three modeling levels; the structural one, the qualitative one, and the quantitative one.

A survey on the resource constrained project scheduling problem has been presented by Ozoama and Ulusoy [12]. In this survey the problem is classified according to specified objectives and constraints. The keys to classification in that survey are number of projects, time-resource function, solution approach, objectives, constraint specification, and type of scheduling. An equation which relate the estimated duration of a resource constrained project to function of various, easily completed, network characteristics are developed and tested by Hall and Evans [5]. The results indicate that in many cases a simple, easy-to-use equation could be employed in a place of a sophisticated scheduling heuristic for estimating project duration

A multi-objective management perspective has been used to arrive at schedules for the best utilization of scarce resources for multiple project-multiple resource-constrained scheduling problems by Mohanty and Sidiq [10]. The analysis is accomplished by means of integer-goal programming and simulation.

A formal definition of semi-active and non-delay schedules for resource-constrained project scheduling problems (RCPSP) has been presented by Sprecher et al [16]. These schedules establish basic concepts within the job-shop scheduling literature. The presented definitions allow deeper in sight concerning the performance of exact and heuristic algorithms. A branch and bound algorithm for project scheduling with resource constraints has been proposed by Christofidels and others [2]. The algorithm is based on the usage of disjunctive arcs for resolving conflicts that are created whenever sets of activities have to be scheduled whose total resource requirements exceed the resource availabilities. One hundred and ten tests were assembled for evaluation three solution procedures for multiple constrained resource project scheduling by Patterson [14]. The investigations show that each procedure was found to be generally superior on a specific class of problems. A new priority based heuristic procedure is proposed for scheduling project activities by Khattab and Choobineh [7]. This procedure attempts to minimize the project duration while satisfying the resource constraints. The numerical comparison shows that the proposed procedure favorals by with a (TIMGEN) technique introduced in [4]. A multiple-tree search procedure for the resource constrained project scheduling problem is presented by Simpson III et al [15]. Computational results are reported both for problems in which resources are available in constant amounts periods, as well as the much more difficult problem in which the resources available are allowed to vary over the schedule horizon. Two algorithms, based on dynamic programming logic for the discrete time/cost trade-off in deterministic activity-on-arc networks of the CPM type, where the duration of each activity is discrete, nonincreasing function of the amount of a single nonrenewable resource committed to it are proposed by Demeulemeester et al [3]. A new model that adequately integrates the merits of LOB and CPM in a mixed integer programming for resource allocation in repetitive projects has been introduced by Korish et al [9]. The virtue of the suggested method lies in its ability to maintain work continuity in the repetitive activities.

PROBLEM FEATURE

In project scheduling under constrained resource statement, the scheduling process must deviate any increase of the resource over the constraint limits. This lead to increase of the completion date due to the activities delays for satisfying resource limitation and activities relations.This means that, the available resources are not in a full usage for certain period of times . In such cases, the excess resources of these specified periods, can be utilized in compression of some critical activities attached to the executed activities in such periods. The compression processes are performed according to their specific regulations and resource availability statements.The proposed algorithm in [1] has been updated in this study for the utilization of the available total slacks on non criticals to be more active and applicable for implementation on PC computers especially for large scale projects. The developed algorithm is written as a program software and checked for validation. The developed mathematical formula which is used as a tool for informing the resource usage under the constrained resource level is:

$$\text{Minimize} \sum_{k=1}^{C} \sum_{j=1}^{L} \sum_{i=ES}^{LF} R_{ijk}^2 \qquad (1)$$

where R_{ijk} is the resource required at duration time i, ES, LF are earlist start and latest finish for activity j, L is the number of non-criticals, and C is the number of iteration cycles which terminates at minimum two consecutive iterations. This procedure is used to uniform the resource usage under the constraint limit. Maximum amounts of resources that are requested for the project execution can be determined by the aids of this updated procedure.

PROPOSED PROCEDURE

The main idea of the proposed procedure is to increase the utilization of the unused resource under the constrained resource level. This unused resource is used to reduce the duration time of some critical activities in the domain where the unused resource exists under the constrained resource level. The compression process increases the resource utility in the specified domain as well as the stated resource constraints are not exceeded. The scheduling process starts with the activities characteristics rendered from the compression process. The heuristic rules used for scheduling process in the current study are:

A- $ROT(m,n) = Max_k \sum_{i,j} CP_{m,n,k} \{R_{i,j}/T_{ij}\}$ (2)

B- $ACTIM(m,n) = Max_k \sum_{i,j} CP_{m,n,k} \{T_{ij}\}$ (3)

C- $ACTRES(m,n) = Max_k \sum_{i,j} CP_{m,n,k} \{T_{ij} R_{i,j}\}$ (4)

D- $GENERS(m,n)/w) = w\,[ACTRES(m,n)/Z_1] + (1-w)\,[ACTIM(m,n)/Z_2]$ (5)

Where n is the set of nodes in the directed network; R_{ij} is the resource required by the activity to be completed; $T_{i,j}$ is the time required by the activity ij to be completed; CP m,n,k is the set of the activities of the kth directed path from the node m to the last node of the network including activity mn; w is a weighting factor, $0 =< w <= 1$; Z_1 is the maximum of {ACTRES (m,n)}; Z_2 is the maximum of {ACTIM (m,n)}. For solving the tackled constrained resource problem, the following assumptions are considered:

1- Network topology and activity duration and resource requirements are known for each activity.
2- The resource requirement of an activity remains constant over the duration of the activity except that the activity is on the critical path, crashable, in the domain of unused resource, and the compression process does not increase the resources over the availability level.
3- The constraint availability of resource level is known (this level is less than the maximum amounts of resources that are obtained by applying the cited algorithm).
4- No pre-emptying is allowed.However, the proposed procedure steps are as follows:

1- The resource skylines at earliest and latest dates are identified.
2- The resource skyline is smoothed.
3- The resource skyline of min-max peak over the constrained resource level is pointed.
4- Determine and arrange according to the cost-function the critical activities that can be compressed within the time horizons of the unused resources.
5- The compression process is applied such that the constrained resource level is not exceeded, otherwise step 8 is applied.
6- If the critical path is changed then go to step 1, otherwise step 7 is applied.
7- Point out the start dates of the project activities after the compression process.
8- The decision rules applied as tie breakers are minimum duration time, minimum required resource, minimum start time, minimum total float, and random.
9- Perform the scheduling process using the considered heuristic rules taking into consideration that the scheduled dates rendered in step 6. The schedule of minimum completion date is considered. In case of no crashing, the starting scheduled dates are those obtained in step 3.

SIMULATED CASE STUDY

In this section, a comparative study has been performed; in case of the application of the stated scheduling heuristic rules before and after the implementation of the proposed procedure, in order to evaluate the effectiveness of the proposed procedure. Six projects each at two different constraint resource levels are considered. The number of activities ranges from 12 to 42 activities and the degree of complexity of the considered projects which is suggested by Pascoe [12](P/N, where P is the number of activities of the project and N is the number of nodes of the same project) ranges from 1.2 to 1.72. Tables (1) to (3) present activity characteristics of the considered projects. Table (4). lists maximum peaks, latest starts, maximum amounts of smoothed resource skylines, and the resource levels under consideration.

Table 1 **Activities characteristics of projects one and two**

Project One

Activity	NR	CR	ND	CD	NC	CC
1 -2	5	7	8	6	288	305
2 - 3	3	4	2	1	72	82
2 - 4	4	5	7	5	300	350
3 - 5	5	6	10	8	500	530
4 - 6	3	4	8	7	300	350
5 - 7	4	4	6	6	330	330
5 - 8	6	8	10	8	500	520
6 - 10	3	3	5	3	320	350
7 - 9	4	6	7	5	300	340
8 - 9	2	3	4	3	310	325
8 - 10	3	3	5	4	310	330
9 - 10	5	6	7	6	200	250

Project two

Activity	NR	CR	ND	CD	NC	CC
1 -2	1	2	4	3	110	130
1 - 3	3	4	5	3	100	120
1 - 4	2	3	8	5	95	110
2 - 3	0	0	0	0	0	0
2 - 5	2	3	5	4	90	130
3 - 5	1	2	6	4	80	90
3 - 6	1	2	4	3	150	180
4 -5	1	1	2	2	70	70
4 - 6	1	1	3	3	100	100
5 - 6	2	3	4	3	200	220
6 - 7	4	5	5	3	110	120
7 - 8	3	4	6	4	200	220
7 -9	2	3	4	3	180	190
8-10	1	2	3	1	300	350
9 - 10	3	4	1	1	220	250

* NR: Normal resource, CC: Crash cost, CR: Crash resource,
* ND: Normal duration, CD: Crash duration, NC: Normal cost
* Resource unit is crew, time unit is day and cost unit is $.

Table 2 **Activities characteristics of projects three and four**

Project three

Activity	NR	CR	ND	CD	NC	CC
1 - 2	5	6	7	5	250	255
2 -3	3	3	2	2	300	300
2 - 4	6	7	4	3	175	200
3 - 5	4	5	3	2	180	200
3 - 7	4	6	10	8	180	210
4 - 7	2	3	5	4	240	250
5 - 6	5	6	3	2	150	260
6 - 9	7	9	5	4	130	150
6 - 11	3	4	2	1	140	150
7 - 8	3	4	4	3	190	220
7 - 13	0	0	0	0	0	0
8 - 12	2	3	2	1	230	250
9 - 10	4	5	3	2	198	230
10 - 14	4	4	2	2	250	250
11 - 14	5	7	3	2	140	150
12 - 13	1	2	2	1	120	130
13 - 15	3	4	3	1	122	135
14 -16	4	4	2	2	223	223
15 - 16	2	4	5	3	200	230
16 - 17	3	3	2	2	180	180
16 - 18	4	5	2	1	250	260
16 -19	4	5	5	4	233	270
17 - 20	5	7	3	2	235	274
18 - 20	4	6	4	3	260	269
19 - 20	2	4	6	4	270	284
20 - 21	5	5	1	1	210	210
21 - 22	5	7	9	8	160	168
21 - 23	4	4	2	2	200	200
22 - 24	4	5	5	3	144	179
23 - 24	3	4	5	4	164	180

project Four

Activity	NR	CR	ND	CD	NC	CC
1 - 2	3	4	1	1	100	100
1 - 3	2	3	1	1	110	110
2 - 4	0	0	0	0	0	0
2 - 15	3	5	14	10	200	220
3 - 4	1	1	1	1	225	225
3 - 5	4	5	2	1	150	165
4 - 6	2	4	4	3	300	315
4 - 15	4	5	6	5	349	359
5 - 7	2	3	3	2	250	266
6 - 8	2	3	7	5	366	378
6 - 9	3	4	2	1	344	350
7 - 15	2	3	4	3	150	200
8 - 9	0	0	0	0	0	0
8 - 10	3	4	2	1	400	410
9 - 11	2	4	3	2	380	399
10 - 11	2	3	2	1	200	210
11 - 12	1	2	4	3	230	233
12 -13	1	1	3	2	245	245
13 - 14	2	2	1	1	200	200
14 - 15	2	4	4	3	180	290
15 - 16	1	1	1	1	100	100
16 - 17	1	3	2	1	105	120

Applying ROT, ACTIM, ACTRES, and GENERS (having weights of 0.0, 0.2, 0.4, 0.6, 0.8, and 1.0) on the considered simulated projects, the completion dates obtained by the scheduling process are postulated in Table (5).

The above table visualizes the scheduling dates of the different projects at the resource levels under consideration. The critical activities that can be shortened in their completion dates within the time horizons as well as increasing the resource utility at the considered resource levels are listed in Table (6).

Applying the proposed procedure using the corresponding heuristic rules which provide minimum completion dates, the completion dates rendered by the scheduling process are listed in Table (7).

Table 3 Activities characteristics of projects five and six

Project Five							Project Six						
Activity	NR	CR	ND	CD	NC	CC	Activity	NR	CR	ND	CD	NC	CC
1 - 2	7	7	4	4	300	300	1 - 2	1	7	7	1	30	69
1 - 3	5	8	9	5	200	210	2 - 3	2	5	5	2	50	68
2 - 21	6	6	3	3	150	150	2 - 4	3	3	4	4	20	20
3 - 4	6	7	5	4	210	230	3 - 5	2	3	3	2	27	45
4 - 5	5	8	7	4	230	210	3 - 7	5	6	15	12	15	26
4 - 7	3	4	9	7	250	270	4 - 7	3	3	5	5	16	16
4 - 21	2	2	4	4	170	170	5 - 6	3	4	3	2	21	24
5 - 6	5	7	8	5	330	350	6 - 9	5	6	5	4	20	30
5 - 7	9	10	7	5	198	210	6 -11	3	4	2	1	40	62
5 - 8	4	4	5	5	200	200	7 - 8	4	5	4	3	21	27
5 - 21	8	8	1	1	160	160	7 - 13	0	0	0	0	0	0
6 - 8	5	5	3	3	230	230	8 - 9	0	0	0	0	0	0
6 - 21	2	4	5	4	250	260	8 - 12	3	3	15	15	13	13
7 - 8	6	6	3	3	160	160	9 - 10	2	3	25	23	16	19
7 - 14	8	9	13	10	150	159	10 - 14	3	4	21	17	16	18
8 - 9	6	8	14	11	220	230	11 - 14	1	3	3	2	24	36
8 - 13	14	15	12	10	230	280	12 - 13	1	1	2	2	20	20
8 - 14	4	4	7	5	133	150	12 - 15	5	5	15	15	43	43
9 - 10	9	10	8	3	400	425	14 - 16	1	2	2	1	20	25
9 - 11	8	9	10	8	360	400	15 - 16	2	4	15	11	30	35
9 - 12	7	7	1	1	250	250	16 - 17	2	3	10	8	20	25
9 - 12	2	2	2	2	240	240	16 - 18	3	4	3	2	10	15
10 - 15	3	4	5	3	260	270	16 - 19	1	1	5	5	30	30
10 - 20	9	10	4	2	170	180	17 - 20	4	5	4	3	60	65
11 - 15	6	7	10	8	300	320	18 - 20	2	3	4	3	37	39
12 - 13	7	8	15	10	285	300	19 -20	4	5	7	6	50	55
12 - 15	14	14	3	3	180	180	20 - 22	3	6	15	16	16	79
13 - 14	5	6	12	10	150	180	22 - 23	1	2	3	1	20	25
13 - 17	8	10	13	7	180	240	22 - 24	1	2	4	2	19	26
13 - 18	1	2	9	6	210	240	22 - 25	1	3	7	4	53	58
14 - 19	7	8	10	7	250	290	23 - 28	3	5	8	7	48	49
15 - 16	6	7	5	3	310	315	24 - 27	2	3	3	2	21	29
15 - 18	3	4	7	4	170	200	25 -26	2	4	5	3	36	56
16 -17	7	8	8	6	320	360	26 - 27	3	4	2	1	14	21
17 - 20	7	8	9	6	420	430	26 - 29	4	5	7	3	21	85
18 - 19	5	5	3	3	310	310	27 - 30	5	6	2	1	13	17
19 - 20	5	5	4	4	150	150	28 - 30	1	2	5	3	18	29
20 - 23	3	3	3	3	430	430	28 - 32	1	3	2	1	12	17
21 - 22	6	7	4	2	240	300	29 - 33	2	2	15	15	15	15
22 - 23	3	4	5	4	155	159	30 - 31	2	3	3	2	18	31
							31 - 33	2	4	4	3	21	34
							32 - 33	2	3	2	1	16	21

Table 4 Maximum peaks and resource levels of the considered projects.

Project No	Maximum peak at ES	Maximum peak at LS	Maximum peak Smoothed	RL 1	RL 2	D.T
P 1	13	14	13	10	8	41
P 2	7	6	7	5	4	29
P 3	16	11	14	10	8	61
P 4	14	11	8	6	4	32
P 5	45	40	28	24	20	91
P 6	13	13	10	8	7	142

* RL1, RL2 are first and second resource levels

* DJ is the project duration

Table 5 The scheduled dates of the considered rules at the resource levels

Rule	P1		P2		P3		P4		P5		P6	
	RL1	R2	RL1	RL2	RL1	RL2	RL1	RL2	RL1	RL2	RL1	RL2
ROT	45	55	32	39	66	87	35	52	100	118	170	171
ACTIM	43	55	32	36	61	75	36	52	98	109	162	168
ACTRES	43	55	32	36	66	80	35	57	98	109	162	168
GENERS(w = 0)	43	55	32	36	61	75	36	52	98	109	162	168
GENERS(w= 0.2)	43	55	32	36	61	77	36	57	98	109	162	168
GENERS(w = 0 .4)	43	55	32	36	61	77	36	57	98	109	162	168
GENERS(w = 0.6)	43	55	32	36	66	80	36	57	98	109	162	168
GENERS(w = 0.8)	43	55	32	36	66	80	35	57	98	109	162	168
GENERS(w = 1.0)	43	55	32	36	66	80	35	57	98	109	162	168

Table 6 Scheduled dates of shortened activities.

P 1						P 2			P 3					
RL1			RL 2			RL 2			RL 1			RL 2		
i - j	T	SD	i -j	T	SD	i - j	T	SD	i - j	T	SD	i - j	T	SD
1 - 2	2	0	1 - 2	2	0	5 - 6	1	16	1 - 2	2	0	1 - 2	2	0
						6 - 7	2	18	8 - 12	1	21	8- 12	1	30
						8 - 10	2	27	12 -13	1	22	12 -13	1	31
									13 - 15	2	23	13 -15	1	35
									19 - 20	2	36	22 - 24	2	65
									22 - 24	2	52			

Table 6 Cont.

P4						P5						P6					
RL 1			RL2			RL1			RL2			RL1			RL2		
i-j	T	SD	i-j	T	SD	i - j	T	SD	i -j	T	SD	i-j	T	SD	i -j	T	SD
16 -17	1	35	16 - 17	1	50	1 - 3	4	0	1 - 3	4	0	1 - 2	6	0	1 -2	6	0
						3 - 4	1	5	3 - 4	1	5	2 - 3	3	1	14-16	1	93
						4 - 5	3	9				3 - 7	12	7	16-17	8	94
						15-16	2	65				14-16	1	69	20-22	6	112
												20 -22	6	85	22-25	3	121
												22 -25	3	94			
												25 -26	2	98			
												26 -29	2	101			

* T is the shortened time, SD is the scheduled date.

Table 7 Completion dates of the projects.

Rule	P1		P2		P3		P4		P5		P6	
	RL1	RL2	RL1	RL2	RL1	RL2	RL1	Rl2	RL1	RL2	RL1	RL2
ACTIM	41	53	28	36	59	70	36	51	88	104	122	152
ACTRES	-	-	-	-	-	-	34	56	-	-	-	-

Figures (1-6) exhibit the resource skylines after scheduling the considered projects using the proposed procedure. The utilization of the available resources (UF% which represents the utilized resources under the constrained resource bound), shortage of resource (SF% which represents the required amounts of resources over the resource bound), and project delays are considered as measuring performance criteria for the considered heuristic rules before and after the implementation of the proposed procedure. However, these measuring performance criteria are exhibited in Table (8).

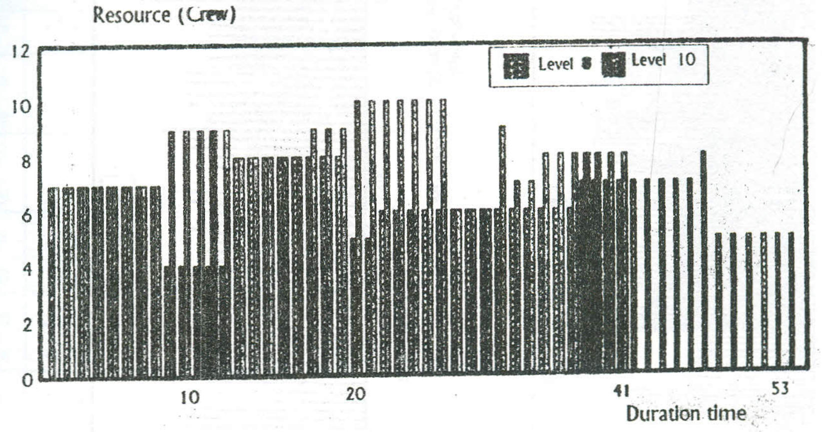

Figure 1. ACTIM resource profile for project 1 after procedure.

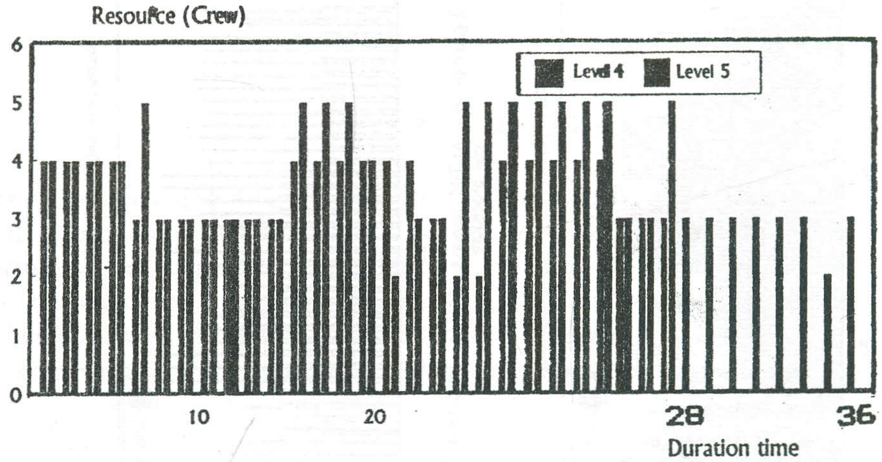

Figure 2. ACTIM resource profile for project 2 after procedure.

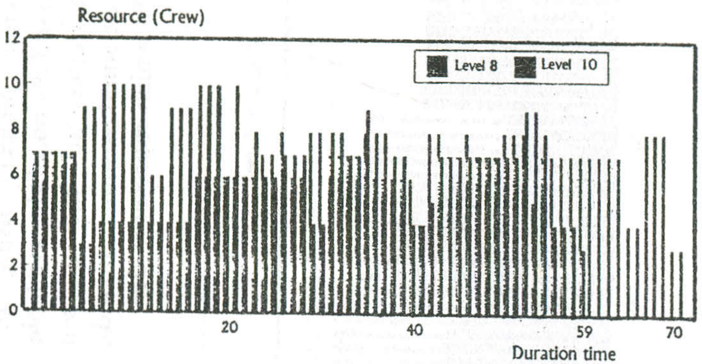

Figure 3. ACTIM resource profile for project 3 after procedure

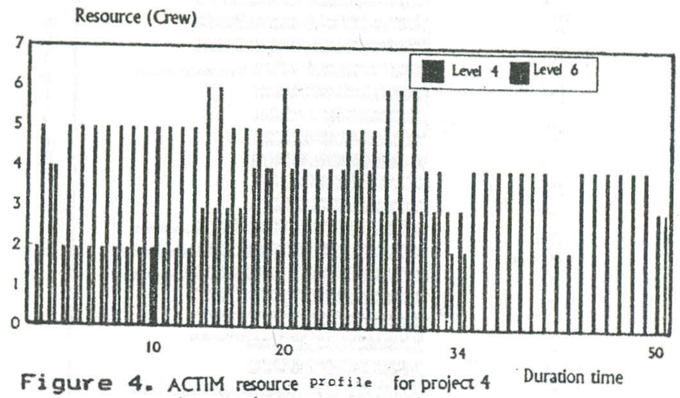

Figure 4. ACTIM resource profile for project 4 after procedure

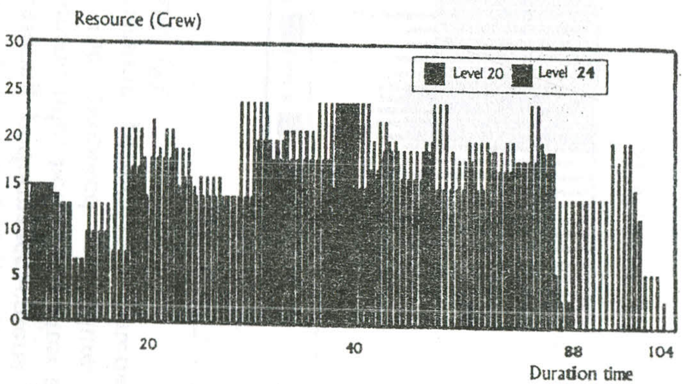

Figure 5. ACTIM resource profile for project 5 after procedure

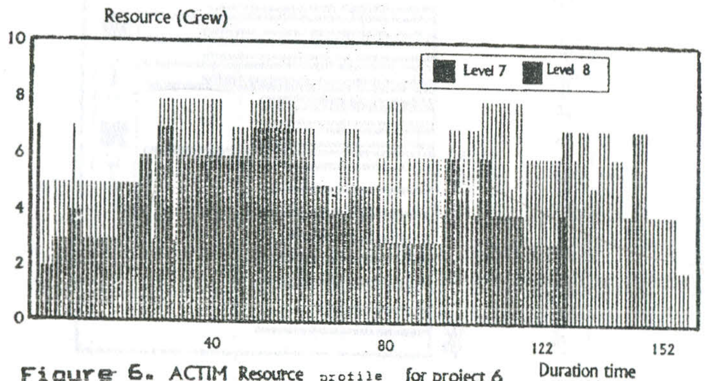

Figure 6. ACTIM Resource profile for project 6 after procedure

Table 8 Scheduling dates and measuring performance criteria

Number of network	Level of resource	ES		LS		Burgess		ROT		ACTIM		ACTRES		GENERS w=8,2,4,6,8		AFTER Precooks ACTIM	
		u.f%	s.f%	u.f%	s.f%	u.f%	s.f%	u.f%	d.t	u.f%	d.t	u.f%	d.t%	u.f%	d.t	u.f%	d.t
1	8	85.67	16.85	79.88	21.65	90.24	11.28	75.68	55	75.68	55	75.68	55	75.68	55	79.01	41
	10	75.37	5.85	71.71	95	79.27	1.95	74	45	77.44	43	77.44	43	77.44	43	81.71	53
2	4	75.1	7.68	80	2.76	80.68	2.06	75	32	75	32	75	32	75	32	80	28
	6	81.89	21.55	92.24	11.21	93.1	10.34	77.92	39	83.33	36	83.33	36	83.33	36	83.33	36
3	8	71.31	17.42	80.12	8.8	80.74	7.99	62.21	87	72.17	75	67.68	80	72.17	75	77.14	70
	10	·62.65	8.03	70	0.98	69.34	1.64	65.61	66	70.98	61	65.61	66	70.98	61	72.2	59
4	6	58.33	23.95	64.06	18.22	77.6	4.68	71.17	37	73.15	36	75.24	35	73.15	36	78.43	34
	4	67.18	56.25	75.78	47.65	92.18	31.25	76.48	52	75.48	52	69.3	57	69.3	57	77.94	51
5	20	80.6	23.24	67.31	23.24	81.76	8.13	69.32	118	75.04	109	75.04	109	75.04	109	78.32	10 4
	24	74.27	12	63.1	12.41	73.44	1.47	68.17	100	7027	97	69.55	98	70.27	97	76.56	
6	8	65	3	62	7	68	1	65	170	59	162	59	162	59	162	76.02	12 2
	7	70	9	66.8	12.2	74	5	64	171	67	168	67	163	64	168	75.48	

CONCLUSION

In this paper, a procedure for scheduling projects of single constrained resource consideration is described. The virtue of the suggested procedure lies in its ability to schedule the projects with less completion dates, delays, as well as higher utilization of resources in comparing with the classical heuristics. Also, the presented development in smoothing algorithm can be considered as a scientific bases for determining the resource bounds at which the execution of projects will be considered either in constrained or unconstrained phase; where it determines the minimum-maximum peak for execution. In such cases, the objective of project execution will be perfectly defined and recognized for project manager and his or her decision can easily be taken.

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