STM JOURNALS
Recent Trends in Civil Engineering & Technology
ISSN: 2249-8753(online), ISSN: 2321-6476(print)
Volume 6, Issue 2
www.stmjournals.com

Time Cost Trade-off and Constraint Resource Scheduling Considering Overtime for Activity Expedition

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Abstract

Project cost, duration and resources are three important parameters of a construction project. There is always a trade-off between project time and cost. While a lot of techniques are available to optimize the project time and cost in normal conditions, less effort is done to optimize them in a resource constraint conditions. This paper is focusing on a nonlinear integer framework for time cost trade-off (TCT) and constraint resource scheduling (RCS) using overtime working as an activity expedition option, taking help of Microsoft project software (MSP) and Microsoft Excel solver. The framework is inspired by the fact that, in case of resource constraints (limited availability), one of the best option for crashing an activity and reducing project duration is increasing working hours (overtime working), considering that the amount of this overtime work should not violate the Indian labor law, the resulted schedule will be the most practical, efficient and with high probability of completion on time.

Keywords: *Time cost trade-off, constrained resource scheduling, labor law, nonlinear integer programming, project total cost*

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INTRODUCTION

Scheduling theory is an important and dynamic subject within combinatorial optimization and has attracted numerous researchers. Scheduling is concerned with the planning of activities over time subject to various side constraints with the intention to minimize some objective functions. First, precedence constraints have to be respected, that is, certain jobs must be completed before others can be executed. During its execution, each job requires capacity of different resources, and the resource availability is mostly limited in real-life situation.

So in project planning in addition to considering priority constraint, planning should be compatible with resources constraints also. While the available literatures describe several techniques to resolve CRS individually, little effort has been devoted to consider CRS with TCT simultaneously because of the higher modeling complexity involved. Rana *et al.* present a nonlinear integer programing model that is developed to solve time-cost optimization, taking into account the flexibility of the schedule (total float loss) [1]. Maghrebi *et al.* introduced a new deterministic mathematical model for time-cost trade-off [2]. Isidore and Back proposed an improved model of the least-cost scheduling technique or the crashing technique in which variability of activities in terms of cost and time is taken into consideration [3]. Elazouni *et al.* presented a multi-objective multimode scheduling optimization algorithm to establish the optimal trade-off between cash, resource and profit [4].

Hu *et al.* presented a time-cost-quality optimization model that enables managers to optimize multi objectives [5,6]. Francis *et al.* proposed a mathematical model based on the modeling strategy underlying the zero-one programming approach, aiming to generate optimum resource constrained schedule under time dependent resource constraint [7]. Creemers incorporated uncertainty of activity duration to the basic RCPSP and called stochastic SRCPSP [8]. Tiwari and Johari introduced a two-step procedure applying TCT and CRS using MS Excel and MSP [9]. Menesi and Hegazy introduced a multimode resource constrained project-scheduling problem (MRCPSP), dealing with projects in which the activities have more than one mode of execution with different resource requirements [10]. Cheng and Tran presented a two-phase differential evolution (DE) model to resolve the multi objective optimization of time-cost tradeoffs in resource constraint [11]. Hegazy and Menesi presented a heuristic method for satisfying both deadline and resource constraints [12-15].

Generally, the project can be accelerated through the addition of resources, e.g. people/equipment, using of advance materials or through addition of working hours to crash activities. But in case of limited resources, we may not add extra resources to expedite an activity or using of advance materials may not be suitable and available for each activity in the schedule. Most of the existing methods didn't consider this fact during TCT+CRS and they simply crashed an activity to the maximum extent. While in case of limited resources, a simple case arises in the use of overtime work, by scheduling weekend or evening work, the completion time for an activity as measured in calendar days will be reduced. Therefore, this paper is focusing on using overtime for TCT+CRS to find an optimum solution satisfying both resource and overtime working hour's constraints.

PROPOSED NLIP FRAMEWORK FOR TCT+CRS USING OVERTIME

A nonlinear-integer programming formulation is used to find the minimum total project cost associated with the optimum duration in constrained resource conditions. The nonlinearity arises from the constraints over activities' relations and precedence. Activities' durations are assumed to be an integer numbers to make it as real as possible.

Framework Parameters

I= Project activities are denoted by the symbol iϵI where I is a set that comprises all project activities, and i=1, 2, 3, …, n;
P= Critical activities are denoted by the symbol pϵP, and p=1,2,3…., n;
Q= Non-critical activities are denoted by the symbol qϵQ, and q=1,2,3…., n;
Faq= Total float of noncritical activity i before crashing;
Fbq= Total float of noncritical activity i after crashing;
NDi= Normal duration of activity i;
CDi= Crash duration of activity i;
CDRi= Current duration of activity i;
TC= Project total cost;
XT= Project targeted completion date;
DC= Project indirect cost;
LTi, j= Lag time between activity i and the succeeding activity j;
COH= Project overhead cost per day;
PND= Penalty days (Number of days beyond the deadline);
DCi= Direct cost of activity i (normal cost);
OWHi= Overtime working hours per labor for activity i;
CCi= Expenditure cost of activity i (crash cost);
NWHi= Normal working hours per labor for activity i;
CUCi= Activity i crashing unit cost/crashing slope;
NWi= Normal Wages per hour per labor for activity i;
NCi= Activity i normal cost;
OF= Overtime factor;
ORC= Overtime cost;
CDAi= Maximum number of days available for crashing for activity i;
ΔDC= Extra direct cost due to crashing;
Rk= Maximum number of resources available;
PUC= Penalty Unit Cost per day;
Ri= Resource assigned to activity i; and
Ra= Sum of resources assigned to each activity on a particular day.

Framework Decision Variables

DT= Project duration;
OWH= Overtime working hours;
Ai= Start time of activity i;
Aj= Start time of succeeding activity j;
Xi= Activity i duration; and
Xj= Succeeding activity j duration.

Resource Constraints

The sum of resources assigned to each activity on a particular day should not be more than the maximum number of available resources.

$$\mathrm{R_a} = \sum_{i=1}^{n} \mathrm{R}_i \leq \mathrm{R}_k \tag{1}$$

Activities Duration Constraints

Each activity has a minimum and maximum duration and activity duration should remain within the allowed limits.

$$CD_p \le CDR_p \le ND_p \tag{2}$$

Activities Relations Constraints
Each project activity is related to its successors through at least one of four relationship types, namely; finish to start (FS), start to start (SS), finish to finish (FF), or start to finish (SF). Considering activity i as the predecessor and j as the successor, these coefficients are FSij, SSij, FFij, SFij. Eqs. (3)–(6) explain the relations between the activities; FS, SS, SF, and FF, respectively:
Finish-to-start relationship (FS):

$$a_i + x_i + LT_{ij} \le a_j \tag{3}$$

Start-to-start relationship (SS):

$$a_i + LT_{ij} \le a_j \tag{4}$$

Start-to-finish relationship (SF):

$$a_i + LT_{ij} \le a_j + x_j \tag{5}$$

Finish-to-finish relationship (FF):

$$a_i + x_i + LT_{ij} \le a_j + x_j \tag{6}$$

Eqs. (7) and (8) explain the forward pass rules while scheduling:

$$ES_j = \text{Max}\left[(ES_i + FS_{ij});\ (ES_i + SS_{ij})\right] \tag{7}$$

$$EF_j = \text{Max}\left[(ES_j + X_j);\ (EF_i + FF_{ij});\ (ES_i + SF_{ij})\right] \tag{8}$$

Eqs. (9) and (10) explain the backward pass rules while scheduling:

$$LF_j = \text{Min}\left[(LS_i - FS_{ji});\ (LF_i - FF_{ji})\right] \tag{9}$$

$$LS_j = \text{Min}\left[(LF_j - X_j);\ (LS_i + SS_{ji});\ (LF_i + SF_{ji})\right] \tag{10}$$

Overtime Working Hour's Constraints
The total number of working hours allotted to a labor pre day as overtime should not violate the labor law requirements (≤2 h/day).

$$OWH_i = \frac{[(ND_i - CDR_i)\, xR_i\, x\ NWH_i/day)]}{CDR_i\, xR_i} \le 2hr/day \tag{11}$$

Objective Functions
There are two objective functions. Each one is needed to be solved in separate steps. First objective function is to minimize the resource requirement on a particular day up to the maximum available limit of resources and within the minimum possible project duration. MSP software is used to overcome these objectives.

$$\text{Minimize} \quad R_a = \sum_{i=1}^{n} R_i \tag{12}$$

The second objective function is to minimize the total project cost according to Eq. (13). MS Excel Solver is used to overcome this objective.
Minimize

$$TC = IDC + DC + \Delta DC + PNC + ORC$$

$$TC = [C_{OH} xD_T + \sum_{i=1}^{n} NC_i + \sum_{i=1}^{n} CUC_i\ x(ND_i - CD_i) + (PNDxPUC) + \sum_{i=1}^{n} OWH_i\, xNW_i\, xOF] \tag{13}$$

Where, IDC is total indirect cost, DC is total direct cost, ΔDC is increase in direct cost due to crashing, PNC is penalty cost for late completion, and ORC is overtime working cost.

Model Application Example
The model application example (Table 1) adopted from Tiwari and Johari, and solved through the proposed NLIP framework for the both scenarios of normal TCT+CRS, and TCT+CRS using overtime for activity expedition [9]. Columns 8, 9 and 10 are added in order to use them in constraint resource scheduling, finding overtime working hours and cost, while columns 11 and 12 are added to perform the stochastic analysis. The indirect cost is assumed to be ≠100/day, the targeted deadline is 10 days and for each day the project spends beyond the deadline (10 days) the contractor is panelized ≠400/day.

Maximum number of resources available is assumed to be three resources per day and an overtime factor of 0.3 is accepted. Figure 1 shows the baseline schedule network, bar chart and resource graph.

Table 1: *Model Application Example, Available Data.*

S. No.	AC	ND, Days	CD, Days	NC ≠	CC ≠	CS ≠	Res	Nwr h/day	Nw ≠/day	Dur. Mean	Dur. Std.Dev
1	A	2	2	400	-	-	2	8	50	2	1
2	B	3	2	600	800	200	3	8	50	3	1.2
3	C	4	2	600	700	50	2	8	40	4	1.3
4	D	6	3	700	1,000	100	1	8	60	6	2
5	E	3	2	500	600	100	3	8	65	3	0.8

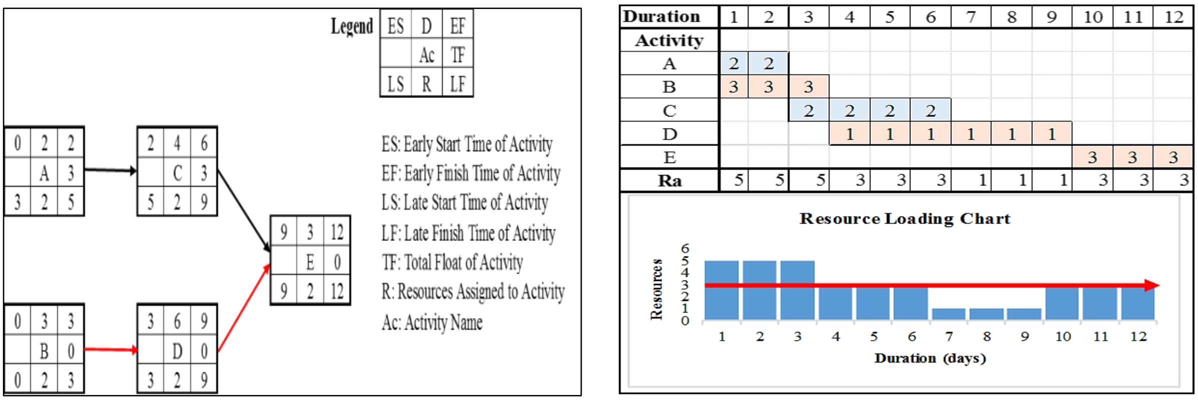

Fig. 1: *Baseline Schedule Network, Bar Chart, and Resource Graph.*

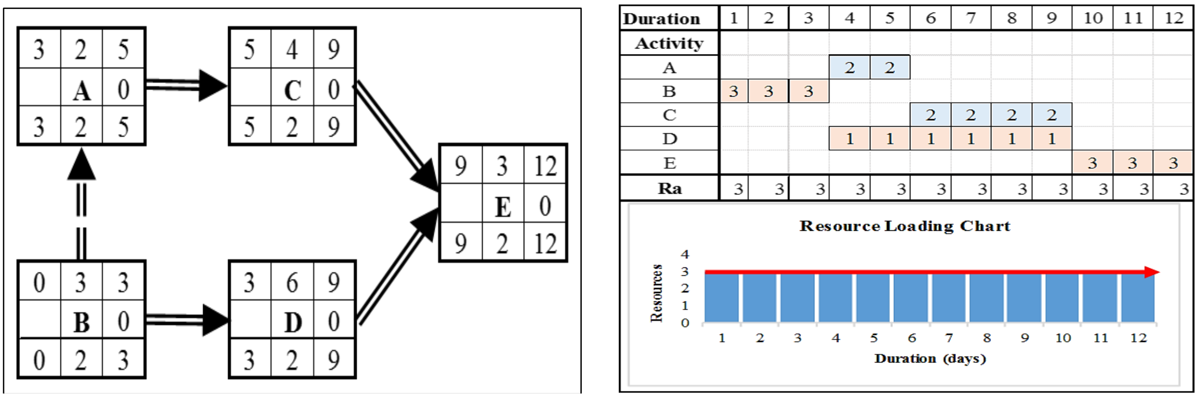

Fig. 2: *Resource Leveled Schedule Network, Bar Chart, and Resource Graph.*

The baseline schedule is loaded to Microsoft project software and after applying resource levelling the resulted project duration is 12 days with ≠4,800 project total cost. Figure 2 shows the baseline schedule network, bar chart and resource graph according to the resource levelled schedule. The network for baseline schedule prepared earlier (Figure 1) modified according to the resource levelled schedule and a finish to start relationship needs to be added between activity B and A based on resource constraints. For application example, such resource constraints are applied through a start delay technique and identified through a dash line in the activities network After applying TCT to the resource levelled schedule using Excel Solver, the optimum duration for normal TCT+CRS is found to be 10 days, and its associated total cost is ≠4,075 satisfying resource constraints. The result is consistent with the one found by Tiwari and Johari [9]. And the optimum duration for TCT+CRS using overtime for activity expedition is 11 days with ≠4,527. To point up the importance of using overtime for TCT in constraint resource conditions, the resulted schedules were compared, then via probability of completion of project on time. The probability of finishing the project within 12 days (normal CRS) is 31.11% with mean of 13.026 and standard deviation of 2.082. The probability of finishing the project within 11 days (TCT+CRS using overtime for activity expedition) is 30.81% with mean of

12.045 and standard deviation of 2.074. The probability of finishing the project within 10 days (normal TCT+CRS) is 29.14% with mean of 11.03 and standard deviation of 2.069. From the previous probabilities found, it can be seen that when overtime is used for activity crashing, the probability of finishing the project is higher than normal case. Figure 3 compares the results between the optimum solution found for normal TCT+CRS and TCT+CRS using overtime in terms of total cost curve.

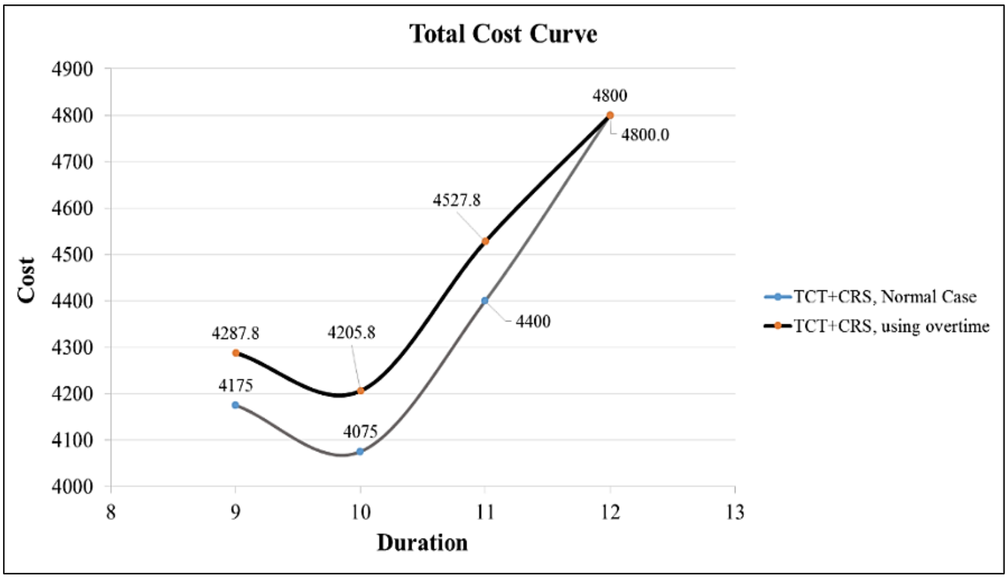

Fig. 3: *Result Comparison between Normal TCT+CRS and TCT+CRS using Overtime.*

From Figure 3, it can be seen that the project total cost and duration in case of using overtime working for crashing and expediting activities, is higher than the project total cost and duration in case of normal TCT+CRS. In this example, this higher cost paid accounts and quantifies the importance of overtime working using for activities crashing in case of limited resource availability, and can save amount associated with risks appearing from project flexibility loss and crushing activity without adding more resources to that. The framework is validated over five examples selected from literature. The probability of finishing the project on time using the developed model in all five cases was better than normal TCT+CRS. Table 2 summarize the results and the resulting probabilities of five examples.

Table 2: *POF Summary of the Five Example Results.*

Example	Normal CRS			TCT+CRS			TCT+CRS using Overtime		
	Project Duration	Total Project Cost	POF %	Project Duration	Total Project Cost	POF %	Project Duration	Total Project Cost	POF %
Example 1 (Isidor and Back)	25	9365	30.36	16	8270	13.42	21	9025.3	20.18
Example 2 (Tarek Hegazy)	18	11000	50	10	10000	49.22	16	10727	50.0
Example 3 (Rana El Haj))	28	14340	24.64	23	13415	17.76	25	13855	22.98
Example 4 (Emad Elbeltagi)	64	47300	44.47	55	45075	25.84	55	45392	26.80
Example 5 (M.Woyeso Geda)	22	84800	47.11	16	76900	43.29	21	82933	47.17

CONCLUSION

In most of the construction projects the deadline and resource limits are two in action constraints that need to be fulfilled together. Normally, the project can be accelerated to meet the deadline through the addition of resources, e.g. people/equipment, using advance materials which can accelerate the activity of completion, or through addition of working hours to crash activities. But in case of constraint resources, the addition of extra resource for crashing of activities may not be a practical option, and using the advance materials may also not be suitable for all the activities. So the best option is to increase the working hours (work overtime). The proposed framework focuses on introducing overtime working hours in to the time cost trade-off in constraint resource condition. In this case the resulting schedule is with longer duration compared to the normal time cost trade-off analysis and with slightly higher total cost, but risk associated with criticality of schedule, delay and completion on time is quite less compared to the normal TCT. The proposed approach is simple enough to be applied manually for educational purposes. The proposed approach has the ability to program as an add-in tool to Microsoft project software for further development.

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Cite this Article

Enayatullah Hemat, Sivakumar MVN. Time Cost Trade-off and Constraint Resource Scheduling Considering Overtime for Activity Expedition. *Recent Trends in Civil Engineering & Technology*. 2016; 6(2): 30–36p.