Application of Earned Value Method on Software Projects in Project Scheduling

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A B S T R A C T

This research is about software project scheduling and use of earned value method on software projects. As a result of the study, a solution for software project scheduling problems is proposed. A mathematical formulation, developed using integer programming method, is at the heart of the solution. Objective of the formulation is to minimize the development costs consisting of direct labor cost, indirect costs and probable penalty costs. The formulation takes the capability and compatibility variances among resources into account whereas contemporary approaches mostly focus on resource availability. Formulation is of type discrete time and takes the time span to be searched as input. Therefore a heuristic approach has been developed for providing time span input to the models developed using the formulation. The heuristic approach has been proven to be calculating a time span that does not hinder achieving the absolute optimum schedule and shortens the solution time of the integer programs. The heuristic approach and problem formulation have been incorporated into a computer program that generates integer programs and heuristic solutions. This research also describes a method for preparing an earned value plan, based on the scheduling solution defined. The method aims to help project managers in determining the status of their projects and deciding whether any corrective action is required or not. Besides the method, approaches for incorporating indirect costs and penalty costs, which are not explicitly discussed in literature, into final cost estimation have been described.

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I N T R O D U C T I O N

The past three decades have been marked by rapid growth of the software industry. However a high ratio of project failure has been recorded and overruns of one or two hundred percent became common during this growth period. Some software projects could not even deliver anything. When the reasons underlying unsuccessful projects were investigated, it was seen that the reasons were mostly related with management.

All these reveal the fact that project management is the key to software project success or failure. Project management is defined as the application of knowledge, skills, tools and techniques to project activity to meet project requirements in Project Management Body of Knowledge (PMBOK) Davis (2003) by Project Management Institute (PMI).

Project management is used as a means to provide planning, organization, direction and control of resources in order to meet an organization’s objectives by a specific date and within a pre-defined budget. Project management involves the application of limited resources to the completion of tasks in the most effective and efficient manner. A pivotal problem of project management is to find the best trade-offs among resources. Support for the coordination of people, tasks, equipment, products, time and money is provided by project management scheduling. Planning and scheduling are often inseparably connected. The plan defines what must be done and restrictions on how to do it while the schedule specifies both how and when it will be done (Brown, 1996). Actually planning and scheduling are common for many engineering domains and numerous studies have been carried out about project scheduling since at least the 950s.

Project scheduling problems are basically made up of activities, resources, precedencereletions, constraints and objective. Constraints define the feasibility of a schedule whereas the objective defines the optimality of the schedule. A feasible schedule is a schedule that satisfies all the constraints. However an optimal schedule not only satisfies all the constraints but is also the best one among all feasible schedules with respect to an objective. Constraints must be satisfied while objectives should be satisfied. Software scheduling can be defined as binding resources to activities on a time scale so as to answer the question of when and by whom each activity of a
Different methods have been proposed and analyzed over a period of approximately fifty years. These studies mostly focused on production and construction industries as these are older disciplines with respect to software engineering. This research proposes a heuristic and an integer programming (IP) model for developing schedules with the objective of cost minimization taking the processing time and cost variances among people into account (Plekhanova, 1998). The IP model provides the optimum schedule while the heuristic method results in a feasible solution instead of the optimum but with a shorter solution time with respect to the IP model. Although both methods aim to minimize costs, the time aspect was not ignored and incorporated into the methods by taking the due date of the project and penalty costs that will be incurred in case the due date is exceeded into account. Actually, the two methods have been designed to be utilized together; however, each can be used independently (Meredith and Mantel, 2005).

As a part of this research study a computer program that implements the heuristic algorithm and generates the IP model has been developed. The program takes the problem parameters as input and uses the two methods discussed above together to generate the related IP model. Besides generating an IP model, the system also constructs a schedule based on the heuristic algorithm and displays the result graphically (Bellenguez, 2004).

In this section, firstly the problem subject to this research study is presented with its general form and also approached from different perspectives so as to clarify the main characteristics and the assumptions of the problem. Consequently, defining the problem, solution approach developed is introduced and results of studies performed on sample projects are presented. Finally, the software developed for automating and implementing the solution approach is presented.

The Scheduling Problem:

The problem subject to this research study is a RCPSP and can be defined as follows with its most general form:

- A project that consists of a set of activities;
- A set of teams to execute the activities;
- A set of constraints to be satisfied and
- An objective to judge a schedule’s performance

What is the best assignment of teams to activities that will produce the best objective while satisfying all the constraints?

Main characteristics and assumptions of the problem are as the following:

- Project is accepted as complete when all the activities constituting the project are completed.
- Network diagram of the project is not cyclic
- Teams may overlap, in other words two different teams may contain one or more individuals in common.
- Overlapping teams cannot be working at the same time.
- Execution time of each activity varies depending on the team assigned to it.

Estimations on how long the execution of each activity would take with each team are made prior to the scheduling phase.

- Complexity of the activities, skill and expertise levels of teams are taken into account while making the activity duration estimations.
- A task can not be started unless all of its predecessors are completed.
- Activities can not be interrupted.
- Only one team can be working on an activity, and a team can be working only on one activity at a time.

Activities:

Activities have estimates of duration and the estimates depend on the knowledge and skill levels of the team executing the activities (Herroelen et al., 2000).

Cost of an activity is dependent upon the team assigned to it since each team completes the activity in different durations and has a different direct labor rate.

An activity once begun may not be stopped nor may the team assigned be changed until the task is completed. Activities have precedence constraints and an activity can not be started unless all of its predecessors have been completed.

Teams:

Teams may be defined as the resources used and required for the execution of activities. Resources may be renewable or nonrenewable and the teams are of type renewable since they are available each period without being depleted (Plekhanova, 2000).

A team may be consisting of a single or many individuals, therefore teams vary in capability and cost due to the variances among individuals. The duration estimations for each job are made by taking the skill variances of
individuals in different teams into consideration. Teams are available in all periods and are allowed to be working on only one activity at a time (Duggan et al., 2004).

As mentioned earlier teams consist of one or more individuals and therefore teams may be overlapping, meaning two or more teams may be including one or more individuals in common. Such teams can not be working at the same time.

**Objective:**

Performance of a schedule is judged based on the “cost at completion” of the project.

Cost at completion is the total costs incurred when the project is completed, and the project is accepted as complete when all the activities constituting the project are complete (Padberg, 2001).

Three main drivers of the cost for the project are:

i) **Direct Labor Cost:**

Each individual has a direct labor rate and is paid according to this rate for each unit of time he/she works for the project. Teams consist of individuals and direct labor rate of a team is the sum of the direct labor rates of the individuals constituting the team. Thus the direct labor cost to be incurred for the project turns out to be:

\[(\text{Direct Labor Cost})_{\text{project}} = \sum_{i} t_i \cdot r_i\]

Where \(t_i\) denotes the length of time that team \(i\) works for the project, while \(r_i\) denotes the direct labor rate of team \(i\).

ii) **Indirect Costs:**

For each unit of time the project continues to be conducted, indirect costs are incurred with a rate called “indirect cost rate”. This rate is constant throughout the project and is independent of the tasks being executed at a specific point in time or the teams working on these activities at this time. It contains the costs like rent of the project office, secretariat costs and other support personnel’s costs. Thus it is possible to say that the longer the project lasts, the higher are the indirect costs to be incurred. So the indirect costs to be incurred for the project turns out to be:

\[(\text{Indirect Cost})_{\text{project}} = (\text{Project Duration}) \times (\text{Indirect Cost Rate})\]

iii) **Penalty Cost:**

Project has a due date which has been agreed upon and tied with the contract. In case the project is completed beyond the due date, the contractor has to pay a penalty for each unit of time the project is late. The amount of penalty cost to be incurred for each unit of time the project is late is called as “penalty cost”.

Consequently, **objective is to find the schedule that minimizes the total cost at completion for the project while satisfying all the constraints.**

**Solution Approach:**

**Problem Formulation:**

Integer Programming (IP) has been utilized for the formulation of the problem. IP is among the widely used exact solution methods of RCPSPs and the major problem with the use of IP is the long solution times. Being aware of this fact a heuristic method has also been developed which helps in shortening the solution times of the IP models.

Objective and the constraints have been defined with IP methods. Constraints define the feasibility of a schedule whereas the objective defines the optimality of the schedule. A feasible schedule is a schedule that satisfies all the constraints. However an optimal schedule not only satisfies all the constraints but is also the best one among all feasible schedules. Goodness is defined by the cost at completion produced by the schedule; the lower the cost is the better is the schedule. So, an optimum schedule turns out to be the feasible schedule which has the least cost at completion.

The IP developed is as the following:

\[j = \text{Activities, } 1...m\]

\[k = \text{Resources, } 1...n\]

\[T = \text{Total number of periods, i.e. the upper bound for the project completion time}\]

\[t = \text{A specific point in time in period } [1, T]\]

\[sk = \text{Direct labor rate of team } k\]

\[I = \text{Indirect cost rate for the project}\]

\[L = \text{Time limit, exceeding which will cause penalty cost to be incurred for each exceeding week, for the project}\]

\[y = \text{Binary variable, } y=1 \text{ if project is completed earlier than } L, y=0 \text{ otherwise}\]

\[P = \text{Penalty cost rate that will be incurred for each unit of time exceeded } L\]
\( B = \) A very big integer
\( K = \) Total penalty cost to be incurred if the time limit \( L \) is exceeded
\( C_{jk} = \) Completion time of activity \( j \) by team \( k \)
\( C_{jkt} = 1 \) if activity \( j \) is completed by team \( k \) on time \( t \); 0 otherwise
\( X_{jkt} = 1 \) if team \( k \) is working on activity \( j \) on time \( t \), 0 otherwise
\( p_{jk} = \) Processing time of activity \( j \) by resource \( k \)
\( P(j) = \) Predecessor set of activity \( j \)
\( H(k) = \) Set of teams that can not work simultaneously with team \( k \)
\( M = \) Objective function

\[
\min \sum_{x} M
\]

Subject to

1) \( \sum_{x} C_{j} = 1 \)

This constraint will ensure that each activity will be completed by only one team at a time. Each activity will be completed by only one team at a time.

2) \( C_{jk} = \sum_{t=1}^{T} t \cdot C_{jkt} \)

This constraint is for the calculation of completion times of the activities. As only one \( C_{jkt} \) in the summation will take the value 1, its multiplication with \( t \) will give the completion time of activity \( j \) by team \( k \) that is \( C_{jk} \).

3) \( \sum_{k} C_{jk} \geq \sum_{z \in k} C_{z} + \sum_{k, j} (p_{jk} \cdot C_{jz}) \quad \forall j, z \in P(j) \)

Third constraint defines the precedence relations among the activities. As \( C_{jk} \) denotes the completion time of activity \( j \) on team \( k \) and will be nonzero only for the team \( k \) that completes it, summing \( C_{jk} \)'s over teams will give the completion time for activity \( j \). This completion time must be greater than or equal to the sum of processing time of activity \( j \) and completion time of any activity \( i \) in its predecessor set.

4) \( X_{jkt} = \sum_{u=t-pjk+1}^{t} C_{jut} \quad \forall j, k, t \)

This constraint ensures that a team \( k \) can be working on an activity \( j \) at time \( t \) if and only if activity \( j \) is completed by team \( k \) in period \([t, t + pjk-1]\).

5) \( \sum_{j} X_{jkt} + \sum_{j, \in P(k)} X_{jkt} \leq 1 \quad \forall k, t \)

This constraint avoids overlapping teams from working at the same time.

6) \( \sum_{j=1}^{n} X_{jkt} \leq 1 \quad \forall k, t \)

6th constraint ensures that a team \( k \) will be working on one activity at a specific time \( t \).

7) \( \sum_{j,k} s_{jk} \cdot X_{jkt} + \sum_{k} I \cdot C_{nik} + K = M \)

Constraint 7 is the constraint where the objective function \( M \) is determined. \( M \) consists of 3 cost elements:
- Direct costs
- Indirect costs
- Penalty cost if exists.

Problem formulation presented above is a discrete time IP model. Time is divided into time units of equal length and \( t \) denotes a specific point of time in period \([1, T]\). The optimum schedule can be presented with a matrix of time, team and activity, which denotes which team will be working on which activity for all \( t \) from 1 to \( T \). The model is presented with black box representation in Figure 1 below.
Heuristic Approach:

As it was stated in previous section, while constructing the model with an upper bound value smaller than Top results in local optimum, constructing with an upper bound value much larger than Top results in long solution times.

In this section, a heuristic method is presented for calculating an upper bound that will ensure achieving the absolute optimum within an acceptable solution time. A study has been carried out on sample projects to see to what extent an improvement does the heuristic provide in solution times.

How to apply the heuristic defined in the former section is described in steps in this part.

Step 1 - Number each activity from the first to the last activity of the project. Start numbering from the first activity, then pass to its immediate successors and number all the activities in the network by this way. For an activity to be numbered all of its predecessors must have already been numbered. The aim of this step is to define a priority rule for the activities. It is also possible to use other priority rules.

Step 2 - For each activity determine the cost of execution by each team. The costs to be taken into account while determining the total cost of a job are:

- Direct Cost
- Indirect Cost
- Penalty Cost

Then the cost of execution of activity $J$ by team $T$ turns out to be:

$$\text{Cost} = P \times (\text{WDLR} + \text{WICR} + \text{WPC})$$

Where WDLR = Weekly direct labor rate of team $T$

WICR = Weekly indirect cost rate for the project

WPC = Weekly penalty cost for the project

P = Processing time of activity $J$ by team $T$

Step 3 - For each activity, determine the team executing that activity with the least cost.

Step 4 - Starting from the first activity, assign each activity to the team that executes it with the minimum cost and locate on a time scale in the order determined in Step 1. While making the assignments, all the activities are assumed to be executed in sequential order without any parallelism.

Step 5 - Taking the real precedence relations of the project network and the resource capacities, shift the activities on the time scale. Start shifting from the first activity of the sequential schedule, continue according to the order of activities in the schedule constructed in Step 4 and assign each activity’s start time to the earliest possible time. Parallel the ones that can be done in parallel in order to shorten the time span of the project without changing any assignment.

Step 6 - Control the finish time of the project. If it is later than the time limit determined for the end of the project, stop. If it is earlier than the time limit, return to step 2, and repeat the steps 2-6, however omit the penalty cost this time.

Examples:

In this part, discussions in the former part are reconsidered and numeric examples for each of them are presented.

First discussion of the former part was about the importance of upper bound for the completion time of the project (T) which was utilized in IP model development. It was stated that the magnitude of T could even affect the result to be achieved since feasible schedules whose time spans are larger than T would not be taken into account while searching for the optimum. In other words choosing a small T may result in achieving a local optimum solution instead of the absolute optimum.

A study has been carried out on a sample project consisting of 15 activities and 3 teams. It was aimed to show the effect of T on the result by this study. Therefore two separate IP models have been generated for the same project with different T values. First model was generated with a T value which is certain to be larger than the time span of the optimum schedule. Such a T value was determined with the following method:
It was assumed that all activities are executed consecutively, and each activity is assigned to the team that completes it in the longest duration. Under these circumstances completion time of the last activity gives the $T$ value that is certain to be greater than or equal to the time span of the optimum schedule since each activity was assigned to the team that executes it in the longest duration.

An example for the application of this method is provided below in Figure 2.

Actually the schedule developed by this method is a feasible schedule and it is possible to construct feasible schedules with longer time spans than this one only by inserting time lags between the consecutive activities. However these time lags will not have any effect except increasing the total cost due to project indirect costs and penalty cost.

The network diagram denotes the activities and precedence relations among the activities while the table shows the execution times of activities separately by teams A and B.

![Network Diagram with Activities and Teams](image)

### Applying the method discussed above results in such a schedule:

<table>
<thead>
<tr>
<th>Team</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>12</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
</tbody>
</table>

**Fig. 2:** Use of the method on a small sample project.

**Earned value management:**

Fleming et al. [18] identify 5 basic steps required to implement earned value management:
1. Define the project scope, preferably with use of a Work Breakdown Structure (WBS)
2. Plan and schedule the project scope.
3. Form Cost Account Plans and budget them to specific functions.
4. Establish and maintain a performance measurement baseline.
5. Monitor project performance and forecast the final results.

Steps defined above are all in parallel with C/SCSC which requires all the work on a contract to be budgeted and scheduled.

One of the most compelling reasons to employ EV management is its ability to provide management with realistic final cost estimates for the project. Thus management can better understand the status of the project at any time and decide whether it is necessary to take any corrective action or not. The two earned value performance indices CPI and SPI constitute the basis for such a decision. These indices can be used both independently and collectively to forecast a range of statistical final cost estimates. By this way an “early warning” signal is provided for project managers to take corrective action and avoid adverse results.

As well as it is possible to make a single point estimate; it is also possible to construct a range for the estimated costs at completion (EAC) on a project using earned value data. This concept is displayed in Figure 3, reflecting a range of “low-end” and “high-end” final cost forecasts. As described by Fleming the following formulas are used to calculate the low end (LE) and the high end (HE) of the range correspondingly.

1. **LE:** $EAC = \frac{\text{Total Budget} - \text{Earned Value}}{\text{Cumulative CPI}} + \text{Actual Costs}$
2. **HE:** $EAC = \frac{\text{Total Budget} - \text{Earned Value}}{(\text{Cumulative CPI} \times \text{SPI})} + \text{Actual Costs}$

First formula is named as “Cumulative CPI EAC” and some people claim that it represents the very minimum while some other claim that it represents the most likely estimate. The second formula is named as
“Cumulative CPI times SPI EAC” and used to incorporate the effect of a poor schedule performance into final cost estimation.

Therefore there are also different ideas about whether it represents the most likely or the worst case EAC. To sum up, it is possible to construct a range for EAC in case of a poor schedule performance by making two estimates, a low end by ignoring schedule performance and a high end by considering the SPI also.

Consequently with the use of two earned value indices, CPI and SPI, it is possible to estimate the final cost requirements for a project, which may either be a single point estimate or a range, enabling the management to make the decision of whether it is necessary or not to take any steps to mitigate the final results. Discussions in the rest of this chapter will be on EAC ranges. Because point estimates will have also been considered by this way as ranges are constructed using two single point estimates.

The proposed method just included the direct labor costs in calculating PV and AC. Therefore the EAC estimation formulas discussed above includes only the direct labor costs. However there exist two other costs that have to be taken into account in EAC calculations. These costs are the penalty cost and the indirect costs which were discussed in detail in Chapter 3. As these costs were included in BAC calculations so that the two values will become comparable. Discussion on incorporating these costs into EAC estimations is presented in the following sections.

Conclusion:
In this section a brief summary of the work accomplished in this research study is provided. Besides providing a summary, limitations of the study and extensions for future research are discussed. Experiencing high ratios of project failure and overruns of one or two hundred percent in software projects during the last three decades directed people to investigate the underlying reasons. The investigations showed that the reasons were mostly related with management. Therefore, project management started to be seen as a key for project success or failure. Project management involves many activities and project scheduling is one of the most important of these activities as it provides the coordination of people, tasks, equipment, products, time and money. However, preparing a good plan and schedule is not enough for project success. As projects are dynamic and carried out in changing environments, monitoring and measuring performance during execution turns out to be another key factor for success. It is necessary to have a monitoring and performance measurement system that generates feedback enabling corrective action to respond to environmental changes. Actually there exists an internationally recognized method for project performance measurement and control, i.e. earned value (EV) method. However, despite its popularity EV has not been widely applied on software projects. Effort spent on this study was towards achieving two main goals,

1. Developing a scheduling system that captures the essence of software projects,
2. Proposing a method for applying EV method on software projects.

In this research, a scheduling system consisting of three components has been developed. These three components are:

i) Problem Formulation

ii) Heuristic Approach

iii) Computer Program that incorporates the above two
Integer programming (IP) method has been utilized for problem formulation. The formulation developed is of type discrete time IP and consists of defining the project constraints and objective by IP methods. A project is comprised of different activities and accepted to be complete when all activities constituting it are completed. Given:
- A project that consists of a set of activities;
- A set of teams to execute the activities;
- A set of constraints to be satisfied.

The formulation aims to find the schedule that enables the completion of the project with minimum cost at completion.

REFERENCES


