Journal of Applied Science and Agriculture, 9(3) March 2014, Pages: 880-887

AENSI Journals

Journal of Applied Science and Agriculture

ISSN 1816-9112

Journal home page: www.aensiweb.com/jasa/index.html

# Application of Earned Value Method on Software Projects in Project Scheduling

Nasim Peykfalak

*Information Technology Department, SanatFoulad Higher Education Institute, Isfahan, Iran*

ARTICLE INFO

*Article history:*
*Received 19 October 2013*
*Received in revised form 16 November 2013*
*Accepted 19 November 2013*
*Available online 20 December 2013*

*Keywords:*
*Software Project Scheduling, Resource Capability, Development Costs,Earned Value Method*

ABSTRACT

This research is about software project scheduling and use of earned value method onsoftware 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 theheart of the solution. Objective of the formulation is to minimize the development costsconsisting 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.



**To Cite This Article:** Nasim Peykfalak., Application of Earned Value Method on Software Projects in Project Scheduling. ***J. Appl. Sci. & Agric.,*** *9(3): 880-887, 2014*

## INTRODUCTION

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 twohundred percent became common during this growth period. Some software projectscould not even deliver anything. When the reasons underlying unsuccessful projectswere 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 isdefined as the application of knowledge, skills, tools and techniques to project activitiesto 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 andcontrol 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 limitedresources to the completion of tasks in the most effective and efficient manner. A pivotalproblem of project management is to find the best trade-offs among resources. Supportfor the coordination of people, tasks, equipment, products, time and money is providedby *project management scheduling*. Planning and scheduling are often inseparablyconnected. The plan defines what must be done and restrictions on how to do it while theschedule specifies both how and when it will be done (Brown, 1996).Actually planning and scheduling are common for many engineering domains andnumerous studies have been carried out about project scheduling since at least the 950s.

Project scheduling problems are basically made up of activities, resources, precedencerelations, constraints and objective. Constraints define the feasibility of a schedulewhereas the objective defines the optimality of the schedule. A feasible schedule is aschedule that satisfies all the constraints. However an optimal schedule not only satisfiesall the constraints but is also the best one among all feasible schedules with respect to anobjective. Constraints *must* be satisfied while objectives *should* be satisfied. Soscheduling can be defined as binding resources to activities on a time scale so as toanswer the question of when and by whom each activity of a

**Corresponding Author:** Nasim Peykfalak, Information Technology Department, SanatFoulad Higher Education Institute, Isfahan, Iran.
E-mail: peykfalak@chmail.ir

project will be conductedand this binding must be done in such a manner that all constraints and precedencerelations must be satisfied with performance measures in mind (Brucker, 1999).

Different methods have been proposed and analyzed over a period of approximately fiftyyears. These studies mostly focused on production and construction industries as theseare older disciplines with respect to software engineering. This research proposes a heuristic and an integer programming (IP) model for developingschedules with the objective of cost minimization taking the processing time and costvariances among people into account (Plekhanova, 1998). The IP model provides the optimum schedulewhile the heuristic method results in a feasible solution instead of the optimum but witha shorter solution time with respect to the IP model. Although both methods aim tominimize costs, the time aspect was not ignored and incorporated into the methods bytaking the due date of the project and penalty costs that will be incurred in case the duedate is exceeded into account. Actually the two methods have been designed to beutilized together; however each can be used independently (Meredith and Mantel, 2005).

As a part of this research study a computer program that implements the heuristicalgorithm and generates the IP model has been developed. The program takes theproblem parameters as input and uses the two methods discussed above together togenerate the related IP model. Besides generating an IP model the system also constructsa 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 itsgeneral form and also approached from different perspectives so as to clarify the maincharacteristics and the assumptions of the problem.Consequent to defining the problem, solution approach developed is introduced andresults of studies performed on sample projects are presented.Finally the software developed for automating and implementing the solution approachis presented.

*The Scheduling Problem:*

The problem subject to this research study is a RCPSP and can be defined as follows withits 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 objectivewhile 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 arecompleted.
- Network diagram of the project is not cyclic
- Teams may overlap, in other words two different teams may contain one or moreindividuals 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 eachteam are made prior to the scheduling phase.

- Complexity of the activities, skill and expertise levels of teams are taken intoaccount 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 onone activity at a time.

*Activities:*

Activities have estimates of duration and the estimates depend on the knowledge andskill 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 completesthe 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 untilthe task is completed.Activities have precedence constraints and an activity can not be started unless all of itspredecessors 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 renewableresources 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 incapability and cost due to the variances among individuals. The duration estimations foreach job are made by taking the skill variances of individuals in different teams intoconsideration.Teams are available in all periods and are allowed to be working on only one activity ata time (Duggan *et al*., 2004).

As mentioned earlier teams consist of one or more individuals and therefore teams maybe overlapping, meaning two or more teams may be including one or more individuals incommon. 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 theproject is accepted as complete when all the activities constituting the project arecomplete (Padberg, 2001).
Three main drivers of the cost for the project are:

*i) Direct Labor Cost:*

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

$$(\text{Direct Labor Cost})_{\text{project}} = \sum_i t_i * r_i$$

Where ti denotes the length of time that team i works for the project, while ridenotes 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 isconstant throughout the project and is independent of the tasks being executed ata specific point in time or the teams working on these activities at this time. Itcontains the costs like rent of the project office, secretariat costs and othersupport personnel's costs. Thus it is possible to say that the longer the projectlasts, the higher are the indirect costs to be incurred. So the indirect costs to beincurred for the project turns out to be:
(Indirect Cost) project = (Project Duration) * (Indirect Cost Rate)

*iii) Penalty Cost:*

Project has a due date which has been agreed upon and tied withthe contract. In case the project is completed beyond the due date, the contractorhas to pay a penalty for each unit of time the project is late. The amount ofpenalty 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 atcompletion 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 isamong the widely used exact solution methods of RCPSPs and the major problem withthe use of IP is the long solution times. Being aware of this fact a heuristic method hasalso 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 thefeasibility of a schedule whereas the objective defines the optimality of the schedule. Afeasible schedule is a schedule that satisfies all the constraints. However an optimalschedule not only satisfies all the constraints but is also the best one among all feasibleschedules. Goodness is defined by the cost at completion produced by the schedule; thelower is the cost the better is the schedule. So, optimum schedule turns out to be thefeasible schedule which has the least cost at completion.
The IP developed is as the following:
**j** = Activities, 1...m
**k** = Resources, 1...n
**T** = Total number of periods, i.e. the upper bound for the project completion time
**t** = A specific point in time in period [1, T]
**sk**= Direct labor rate of team k
**I** = Indirect cost rate for the project
**L** = Time limit, exceeding which will cause penalty cost to be incurred for eachexceeding week, for the project
**y** = Binary variable, y=1 if project is completed earlier than L, y=0 otherwise
**P** = Penalty cost rate that will be incurred for each unit of time exceeded L

**Journal of Applied Science and Agriculture, 9(3) March 2014, Pages: 880-887**

**B =** A very big integer
**K =** Total penalty cost to be incurred if the time limit L is exceeded
**Cjk**= Completion time of activity j by team k
**Cjkt**is 1 if activity j is completed by team k on time t; 0 otherwise
**Xjk**tis 1 if team k is working on activity j on time t, 0 otherwise
**pjk**= 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

$$\min \sum_{k} M$$

**Subject to**

$$1) \sum_{k,t} C_{jkt} = 1$$

This constraint will ensure that each activity will be completed by only one team at atime t.each activity will be completed by only one team at atime t.

$$2) C_{jk} = \sum_{t=1...T} t * C_{jkt}$$

This constraint is for the calculation of completion times of the activities. As only oneCjktin the summation will take the value 1, its multiplication with t will give thecompletion time of activity j by team k that is Cjk.

$$3) \sum_{k} C_{jk} \geq \sum_{z,k} C_{zk} + \sum_{k,t} (p_{jk} * C_{jkt}) \qquad \forall j, z \in P(j)$$

Third constraint defines the precedence relations among the activities. As **Cjk**denotesthe completion time of activity j on team k and will be nonzero only for the team k thatcompletes it, summing **Cjk**'s over teams will give the completion time for activity j. Thiscompletion time must be greater than or equal to the sum of processing time of activity jand completion time of any activity in its predecessor set.

$$4) X_{jkt} = \sum_{u=t,t+pjk-1} C_{jku} \qquad \forall j, k, t$$

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

$$5) \sum_{j} X_{jkt} + \sum_{j,e \in H(k)} X_{jet} \leq 1 \qquad \forall k, t$$

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

$$6) \sum_{j=1...n} X_{jkt} \leq 1 \qquad \forall k, t$$

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

$$7) \sum_{j,k,t} s_k * X_{jkt} + \sum_{k} I * C_{mk} + K = M$$

Constraint 7 is the constraint where the objective function M is determined. M consistsof 3 cost elements:
Direct costs
Indirect costs
Penalty cost if exists.

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

Journal of Applied Science and Agriculture, 9(3) March 2014, Pages: 880-887

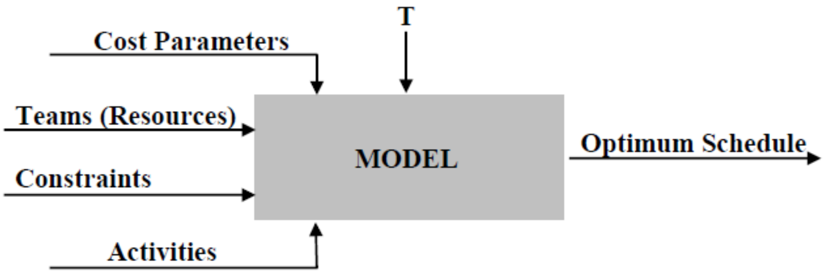



**Fig. 1:** Black box representation of the model.

*Heuristic Approach:*

As it was stated in previous section, while constructing the model with an upper boundvalue smaller than Topthinders achieving the optimum solution, constructing with anupper bound value much larger than Toptresults in long solution times.

In this section, a heuristic method is presented for calculating an upper bound that willensure achieving the absolute optimum within an acceptable solution time. A study hasbeen carried out on sample projects to see to what extent an improvement does theheuristic 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. Startnumbering from the first activity, then pass to its immediate successors andnumber all the activities in the network by this way. For an activity to benumbered all of its predecessors must have already been numbered. The aim ofthis step is to define a priority rule for the activities. It is also possible to useother priority rules.

***Step 2*** - For each activity determine the cost of execution by each team. The costs tobetaken into account while determining 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:

Cost = P * (WDLR + WICR + 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 itwith 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 beexecuted in sequential order without any parallelism.

***Step 5*** - Taking the real precedence relations of the project network and the resourcecapacities shift the activities on the time scale. Start shifting from the firstactivity of the sequential schedule, continue according to the order of activitiesin the schedule constructed in Step 4 and assign each activity's start time to theearliest possible time. Parallel the ones that can be done in parallel in order toshorten 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 determinedfor the end of the project, stop. If it is earlier than the time limit, return to step2, 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 foreach of them are presented.

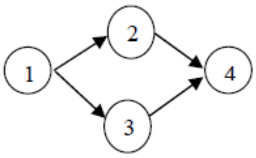
First discussion of the former part was about the importance of upper bound for thecompletion time of the project (T) which was utilized in IP model development. It wasstated that the magnitude of T could even affect the result to be achieved since feasibleschedules whose time spans are larger than T would not be taken into account whilesearching for the optimum. In other words choosing a small T may result in achieving alocal 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 Ton the result by this study. Therefore two separate IP models have been generated for thesame project with different T values. First model was generated with a T value which iscertain to be larger than the time span of the optimum schedule. Such a T value wasdetermined with the following method:

*It was assumed that all activities are executed consecutively, and each activity isassigned to the team that completes it in the longest duration. Under thesecircumstances completion time of the last activity gives the T value that is certain to begreater than or equal to the time span of the optimum schedule since each activity wasassigned 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 possibleto construct feasible schedules with longer time spans than this one only by insertingtime lags between the consecutive activities. However these time lags will not have anyeffect 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.




| ACTIVITIES | TEAMS A | TEAMS B |
|---|---|---|
| 1 | 10 | 15 |
| 2 | 12 | 9 |
| 3 | 13 | 16 |
| 4 | 7 | 4 |

pplying the method discussed above results in such a schedule:


| | | | | |
|---|---|---|---|---|
| Team: | B | A | B | A |
| Duration: | 15 | 12 | 16 | 7 |

Project Completion Time: 15 + 12 + 16 + 7 = 50

**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 acontract to be budgeted and scheduled.

One of the most compelling reasons to employ EV management is its ability to providemanagement with realistic final cost estimates for the project. Thus management canbetter understand the status of the project at any time and decide whether it is necessaryto 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 bothindependently and collectively to forecast a range of statistical final cost estimates. Bythis 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 arange 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 lowend (LE) and the high end (HE) of the range correspondingly.

**(1) LE:** *EAC = (Total Budget – Earned Value) / Cumulative CPI + Actual Costs*
**(2) HE:** *EAC = (Total Budget – Earned Value) / (Cumulative CPI x SPI) + Actual Costs*

First formula is named as “Cumulative CPI EAC” and some people claim that itrepresents the very minimum while some other claim that it represents the most likely estimate. The second formula is named as

Journal of Applied Science and Agriculture, 9(3) March 2014, Pages: 880-887

“Cumulative CPI times SPI EAC” and used toincorporate the effect of a poor schedule performance into final cost estimation.

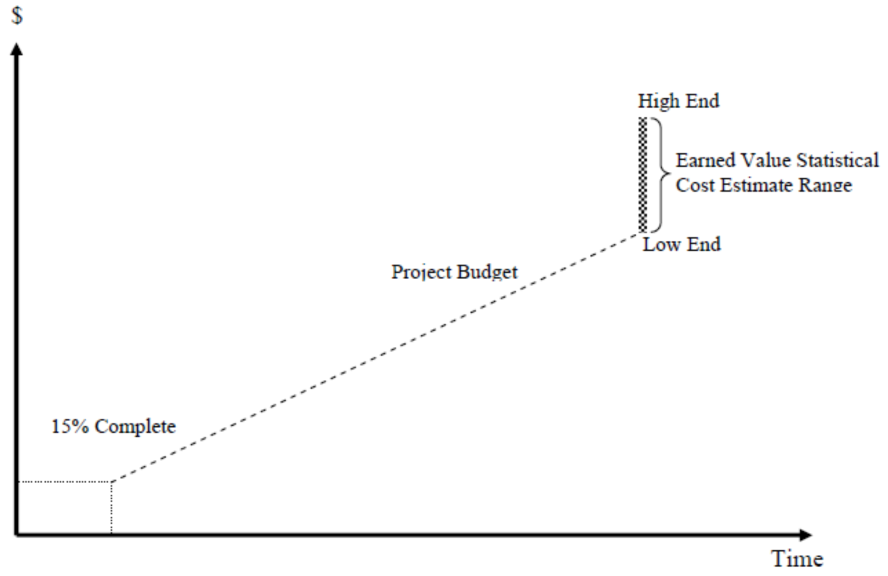



**Fig. 3:** EAC range.

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

Consequently with the use of two earned value indices, CPI and SPI, it is possible toestimate the final cost requirements for a project, which may either be a single pointestimate or a range, enabling the management to make the decision of whether it isnecessary or not to take any steps to mitigate the final results. Discussions in the rest ofthis chapter will be on EAC ranges. Because point estimates will have also beenconsidered 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 laborcosts. However there exist two other costs that have to be taken into account in EACcalculations. These costs are the *penalty cost* and the *indirect costs* which werediscussed in detail in Chapter 3. As these costs were included in BAC calculations theymust also be included in EAC calculations so that the two values will becomecomparable. Discussion on incorporating these costs into EAC estimations is presentedin the following sections.

*Conclusion:*

In this section a brief summary of the work accomplished in this research study isprovided. Besides providing a summary, limitations of the study and extensions forfuture research are discussed.Experiencing high ratios of project failure and overruns of one or two hundred percent insoftware projects during the last three decades directed people to investigate theunderlying reasons. The investigations showed that the reasons were mostly related withmanagement. Therefore, project management started to be seen as a key for projectsuccess 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. Asprojects are dynamic and carried out in changing environments, monitoring andmeasuring performance during execution turns out to be another key factor for success.It is necessary to have a monitoring and performance measurement system that generatesfeedback enabling corrective action to respond to environmental changes.Actually there exists an internationally recognized method for project performancemeasurement and control, i.e. earned value (EV) method. However, despite itspopularity EV has not been widely applied on software projects.Effort spent on this study was towards achieving two main goals,

Developing a scheduling system that captures the essence of software projects,

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

**Journal of Applied Science and Agriculture, 9(3) March 2014, Pages: 880-887**

Integer programming (IP) method has been utilized for problem formulation. Theformulation developed is of type discrete time IP and consists of defining the projectconstraints and objective by IP methods. A project is comprised of different activitiesand 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 withminimum cost at completion.

## REFERENCES


Brown, N., 1996. Industrial-Strength Management Strategies.CROSSTALK – TheJournal of Defense Software Engineering, Report of the Defense Science Task Force on Military Software.

Plekhanova, V., 1998. On Project Management Scheduling where Human Resourceis a Critical Variable. Proceedings of the 6th European Workshop on SoftwareProcess Technology (EWSPT-6).

Meredith, J.R., S.J. Mantel, 2005. Project management: a managerial approach 4$^{th}$ed. New York: Wiley.

Davis, E.W., 2003. Project Scheduling Under Resource Constraints HistoricalReview and Categorization of Procedures, AIIE Transactions, 5: 297-313.

Brucker, P., A. Drexl, R. Möhring, K. Neumann, E. Pesch, 1999. Resource Constrained Project Scheduling: Notation, classification models, and methods, EJOR, 112: 3-41.

Bellenguez, O., 2004. A Multi-Skill Project Scheduling Problem, Available:http://www.univ-tours.fr/ed/edsst/comm2004/bellenguez.pdf.

Herroelen, W., R. Leus, E. Demeulemeester, 2002. Critical Chain Project Scheduling: Do Not Oversimplify, Project Management Journal, 33: 48-60.

Plekhanova, V., 2000. On the Compatibility of Contemporary Project Management Tools with Software Project Management.Proceedings of the 4th World Multiconference on Systemics, Cybernetics and Informatics (SCI'2000) and the 6$^{th}$International Conference on Information Systems Analysis and Synresearch.

Duggan, J., J. Byrne, G.J. Lyons, 2004. A task allocation optimizer for softwareconstruction. Software, IEEE, 21: 76-82.

Padberg, F., 2001. Scheduling Software Projects to Minimize theDevelopmentTime and Cost with a Given Staff. Proceedings of the Asia Pacific Software Engineering Conference APSEC, 8: 187-194.