MULTI OBJECTIVE ANALYSIS FOR TIMEBOXING MODELS OF SOFTWARE DEVELOPMENT

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Abstract: In iterative/incremental software development, software deliverables are built in iterations - each iteration providing parts of the required software functionality. To better manage and monitor resources, plan and deliverables, iterations are usually performed during specific time periods, so called "time boxes". Each time box is further divided into a sequence of stages and a dedicated development team is assigned to each stage. Iterations can be performed in parallel to reduce the project completion time by exploiting a "pipelining" concept, that is, when a team completes the tasks of a stage, it hands over the intermediate deliverables to the team executing the next stage and then starts executing the same stage in the next iteration. In this paper, we address the problem of optimizing the schedule of a software project that follows an iterative, timeboxing process model. A multi objective linear programming technique is introduced to consider multiple parameters, such as the project duration, the work discontinuities of development teams in successive iterations and the release (delivery) time of software deliverables. The proposed model can be used to generate alternative project plans based on the relative importance of these parameters.

1 INTRODUCTION

In iterative and incremental development, software is built gradually by following a sequence of iterations, with each of the iterations delivering a part of the final software system (Larman, 2003). A common project management technique that has been associated with iterative/incremental software processes (e.g., Rational Unified Process - RUP, Dynamic Systems Development Method - DSDM) is timeboxing (Hunt, 2003; Stapleton, 2003). In timeboxing, iterations are performed during specific time periods, so called "time boxes". The timeboxing model is suitable for software development projects in which delivery times are crucial and system requirements are stable or, at least, they can be grouped into classes of features to be developed during different time boxes/iterations.

The main objective of timeboxing is to deliver the final software system as quickly as possible and avoid risks of missing project deadlines (Jalote *et al.*, 2004). Each time box is divided into a sequence of stages (e.g., requirements analysis, design, implementation, testing and deployment) that are repeated in each time box (Figure 1). A dedicated team of experts is usually assigned to each stage, i.e., a team for a stage performs only the activities for that stage. Iterations in timeboxing can be performed in parallel to further improve the project performance and reduce the overall project duration. Parallelism is achieved by exploiting a "pipelining" concept from hardware architectures (Hennesy and Patterson, 2004), that is, when a team completes the tasks of a stage, it hands over the intermediate deliverables to another team executing the next stage and then starts executing the same stage in the next timeboxed iteration.

However, the application of a timeboxing process model is often associated with some "inherent" assumptions/simplifications which require proper configuration/resource management procedures (Jalote *et al.*, 2004):

- the number and duration of time boxes are fixed,
- the planned durations of each stage, in each time box, are approximately equal,
- precedence constraints between stages, in each iteration, are simple sequential relationships,

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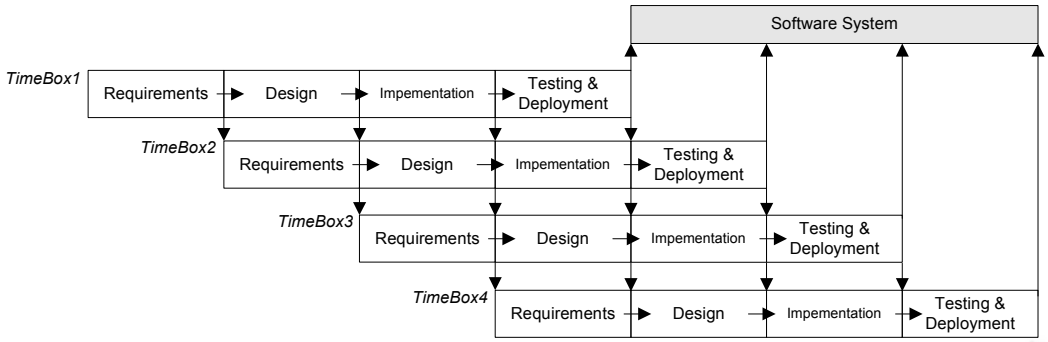


Figure 1: The timeboxing process model.

- requirements, system architecture and technology are considered as quite stable to be managed separately into different time boxes/iterations,
- development teams, performing the same type of activity at respective stages in different timeboxed iterations, should be experienced and "coherent" enough to ensure high resource utilization and avoid idle times/work discontinuities in successive iterations.

A serious drawback of timeboxing is that possible work discontinuities affecting the project velocity (XP, 2006) cannot be easily handled. For example, even with a highly experienced team of designers, execution of activities in the corresponding stage of a particular time box/iteration cannot be performed "immediately" after the same (or a different) team has completed the activities of the design stage in the previous time box. In reality, due to the different scope of the design activities (database system design, user interface design etc.), software projects require larger amount of resources (e.g., multi-disciplined designers), thus raising coordination issues, transition/communication delays and resource time losses between design stages in successive iterations. Consequently, there is a learning curve associated with any team to become familiar with the features to be implemented at each stage and the corresponding user requirements (Hanakawa *et al.*, 1998). Furthermore, in a multi site software development project (Ebert and De Neve, 2001), members of development teams may be drawn from several locations, thus introducing additional communication gaps/coordination delays. Even when the system architecture is quite fixed (e.g., in a software project developing a web application), the set of features to be considered during the design stage of a specific iteration depends on the outcomes of the previous requirements stage and any new requirements introduced by the end-user. In such cases, the development of a software project based on a "rigid" timeboxing approach is getting much more complex and should be supported with more systematic and holistic methodologies that address diverse scheduling decision elements, regarding the overall project performance.

This paper, contributes to further promote the applicability of the timeboxing process model in software projects that require more effective resource management and planning, by exploring the multi objective approach in planning and scheduling decisions. In particular, we propose a multi objective linear programming (LP) model for scheduling projects which employ timeboxing (TB projects). The model includes a list of criteria (such as project duration, iteration completion/release time of software increments and work gaps), which are important for TB project managers in making decisions regarding the overall project performance. Thus, the scheduling problem of TB projects is regarded as a multi criteria decision that can be formulated by linear programming techniques. Such a Multi Criteria Decision Analysis (MCDA) approach is based on a parametric objective function which, according to the values of its parameters, aims either at a single criterion optimization or at a multi-objective optimization, by combining different criteria into a single cost criterion for the whole project.

The rest of the paper is organized as follows: Section 2 describes the background of our approach. Section 3 presents a formal linear programming formulation for scheduling TB software projects. Section 4 presents the application of the model to a software project example that follows practices of iterative/timeboxed planning as well as the project schedule evaluation under individual criteria. Section 5 presents the project schedule evaluation by considering multiple criteria; the model utilization to assist software project managers in selecting among alternative project schedules is also discussed.

Finally, conclusions and directions of future research are discussed in section 6.

2 BACKGROUND

While MCDA approaches have been applied in other fields of software engineering and software project management, there is a lack of attention to the problem of efficiently scheduling iterative software development, in general, and TB projects, in particular. For example, in (Lai *et al.*, 2002; Santhanam and Kyparisis, 1995) MCDA techniques have been proposed to assist the problem of selecting a software development project from a set of projects by considering the cost of the respective investment; in (Wang and Lin, 2003; Ruhe *et al.*, 2003) MCDA techniques have been suggested to select and prioritise software requirements; in (Stamelos and Tsoukias, 2003) a multi criteria model has been applied to evaluate the software quality; while in (Barcus and Montibeller, 2006) MCDA has been employed to support work allocation in distributed software development teams.

With regard to TB project scheduling, Jalote *et al.*, (2004) examine the cost of unequal stages to the overall performance and resource utilization of a TB project. In their paper, the pipelining concept from hardware architectures is exploited to provide a process model for TB projects and, consequently, to determine the overall project duration, in case that time boxes are decomposed into unequal stages. Each stage is considered equal to the longest stage; the frequency of deliverables produced (i.e., the project velocity), as well as the project duration are determined by the longest stage. The model application results in "slack time" for the teams performing the "slower" stages (i.e., resources under-utilization). The problem is handled in an ad-hoc way by reducing the size of teams for the slower stages. In addition, the suggested approach assumes a simplified nature for TB projects where: i) the number/duration of timeboxes/stages is fixed and pre-specified, ii) there are no transition delays (work gaps) between stages in successive iterations, and iii) in each timeboxed iteration, stages proceed at a sequential manner. Hence, the model does not take into account multiple decision elements for scheduling TB projects, such as the project duration, the completion time of each iteration that determines the time of the next software release increment, possible precedence relationships due to technological constraints between stages, as well as transition delays/work discontinuities between stages in successive iterations.

To alleviate the above limitations, in this paper we try to exploit recent advances of MCDA in other project management areas which exhibit analogous characteristics to TB software projects. For example, many instances of construction engineering projects consist of a set of activities that are repeated at different locations/units (Mattila and Abraham, 1998). After an activity is completed in one site, it is repeated in the next site either at a horizontal (highway segments, railways bridges, tunnels, pipelines, sewers etc.) or a vertical flow (high-rise and multi-story buildings, multi-housing projects, etc.) These projects are known in the construction engineering literature as Linear and Repetitive Projects (LRPs) (Hassanein and Moselhi, 2005). Scheduling of LRPs, in practice, could involve multiple control variables than just minimizing the project duration or achieving resource continuity, which are the objectives in conventional project scheduling techniques like PERT/CPM and RSM (Repetitive Scheduling Method), respectively (Kallantzis and Lambropoulos, 2004; Yang and Ioannou, 2004). Alternative project schedules, comparisons and cost trade-offs are often required to arrive at an acceptable or optimum project schedule. In this aspect, the scheduling problem in LRPs has been recently considered as a multi objective problem that can be addressed by linear programming techniques (Hassanein and Moselhi, 2005; Hyari and El-Rayes, 2006; Ipsilandis, 2007). In the following, a multi objective linear programming scheduling model, originally defined for LRPs (Ipsilandis, 2007), is adapted to schedule software projects which employ timeboxing. The model has the capacity to provide optimum schedules, reflecting not only single but multiple objectives, and assist software project managers in producing and selecting among alternative schedules of a TB project.

3 THE MULTI OBJECTIVE NATURE OF TB PROJECTS

In a TB project, a list of criteria important to the software project manager in his/her decision making regarding the overall project performance may include the following:

- Project duration.
- Resource idle time: in TB projects, work gaps between stages in successive timeboxed

iterations cannot be ignored. Although the same stage is repeated sequentially in different timeboxes, violating the continuity of the same stage between successive timeboxes introduces work gaps and time losses that increase the overall project cost and duration.

- Iteration completion time: The completion of each iteration and, consequently, the time of the next software release increment are affected by the precedence relationships/technological constraints between stages and the duration of each stage. The iteration completion time identifies a proper choice/milestone (i.e., a minimum bound) for the duration of the corresponding time box and, thus, specifies the iteration deadline. The project manager can then identify the amount of functionality to be developed at each iteration, that is, the functionality that can be "fit" into a time box. Iterations result in some working software released to the customer for early feedback or to the Quality Assurance team. The final iteration results in the final software product.
- Slack time: Reducing a stage slack time may result in achieving a high level of work continuity and resource utilization but, at the same time, introduces higher risk, regarding the completion time of iterations and the overall project duration.
- Number of iterations: A TB project requires a good estimation of the software features to be developed and released after each iteration. We assume that each iteration introduces an additional fixed cost for the project but, at the same time, splits the software system into smaller parts which could improve the overall cash flow and keep management complexity under control.

In any TB project, there is a set of M stages and P project dependency relationships (with or without time-lag). The project is divided into N separate iterations in a "linear" way, where, without loss of generality, the following assumptions hold: i) all stages are performed in all iterations, ii) a stage cannot be performed in any iteration before the same stage is completed in the previous iteration, and iii) the set of precedence dependencies remain the same in all iterations (i.e., the same planning method is followed in all iterations).

Let $i = 1,2,...,M$ denote the project stages and $j = 1,2,...,N$ denote the project iterations. Scheduling of a TB project can be formulated as a linear programming model as follows.

Model Variable and Parameters.
Define:

d_{ij} , the duration of stage i in iteration j,

s_{ij}, f_{ij} , the start and finish time respectively of stage i in iteration j,

l_{ij} , the minimum elapsed time for starting stage i in iteration j+1, after finishing stage i in iteration j,

P_i , the set of predecessor stages to stage i,

E , the set of all stages without successors,

WB_i, the total duration of work-breaks for stage i because of discontinuities in successive iterations,

UC_j, the completion time of iteration j,

D_j , the promised delivery/release time for the software part produced in iteration j,

c_j , the unit cost of delay in finishing iteration j after the deadline (timebox),

f_i , the unit cost of work-breaks in stage i.

Constraint definitions.
Define:

Stage duration constraints:

$$f_{ij} = s_{ij} + d_{ij} \quad \forall i=1, 2...M, j=1, 2... N \tag{1}$$

Project linearity constraints:

$$s_{ij+1} \geq f_{ij} + l_{ij} \quad \forall \ i=1, 2... M, j=1, 2... N-1 \tag{2}$$

When $l_{ij} = 0$, the constraint takes the form of the common finish-to-start relationship.

Technological dependencies:

$$s_{ij} \geq f_{kj} \quad \forall i=1, 2... M, j=1, 2...N, k \in P_i \tag{3}$$

Iteration completion time:

$$UC_j \geq f_{kj} \quad \forall j=1,2...N, k \in E \tag{4}$$

UC_j is the completion time for iteration j and UC_N is equal to the project duration.

Resource delays (work-breaks):

$$WB_i = \sum_{j=1}^{N-1} (s_{ij+1} - f_{ij}), \quad \forall \ i = 1,...,M$$

$$WB = \sum_{i=1}^{M} WB_i \tag{5}$$

Global Objective function.
Depending on the values of the parameters c_j and f_i the following general objective function:

$$\text{Minimize} \sum_{j=1}^{N} c_j.(UC_j - D_j) + \sum_{i=1}^{M} f_i.WB_i \tag{6}$$

can be used accordingly, to achieve different objectives or for trade-offs between various criteria, as follows:

Project duration (c_N =1, rest of c_j and f_i equal to 0):

$$\text{Minimize} UC_N \tag{7}$$

Total work-break time (all f_i = 1, all c_j = 0):

$$\text{Minimize } WB \tag{8}$$

Iteration completion time (all f_i = 0, c_j = 1):

$$\text{Minimize} \sum_{i=1}^{M} UC_i \quad (9)$$

Total cost of work-breaks (all $c_j = 0$):

$$\text{Minimize} \sum_{i=1}^{M} f_i.WB_i \quad (10)$$

Delay cost (all $f_i = 0$):

$$\text{Minimize} \sum_{i=1}^{M|} c_j.(UC_j - D_j) \quad (11)$$

Trade-offs between costs of project delays and resource delays (work-breaks):

$$\text{Minimize} \sum_{j=1}^{N} c_j.(UC_j - D_j) + \sum_{i=1}^{M} f_i.WB_i \quad (12)$$

4 CASE-STUDY EXAMPLE

In this section, we demonstrate the type of answers and analysis that can be supported by the proposed model through the use of a hypothetical short-term software project example that follows the principles of the agile ICONIX process (Rosenberg *et al.* 2005). In ICONIX, the project processes are use-case driven, like in RUP, but without a lot of the project management overhead that the RUP introduces. The project example follows a minimal set of 6 stages/steps which are executed in an iterative/incremental approach. These stages are: Domain Modelling (stage A), Use-Cases Analysis (stage B), Requirements Review (stage C), Preliminary Design & Review (stage D), Detailed Design & Review (stage F) and Coding & Testing (stage F).

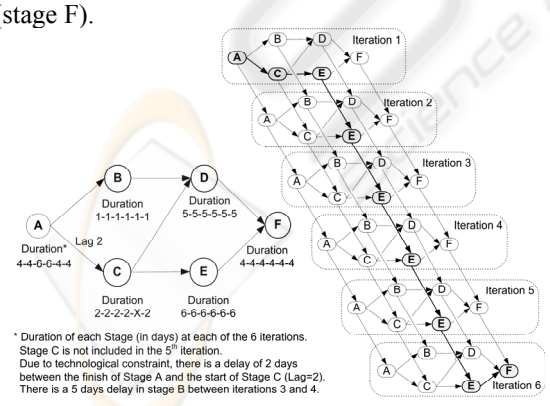


Figure 2: Precedence and PERT network.

Multiple iterations occur between developing the domain model (stage A) and analyzing the use cases (stage B). Other iterations exist, as well, as the development proceeds through the project life cycle. Although the project does not require a lot of bookkeeping, in order to over-utilize the small development teams working at each stage (2-3 experts), all iterations should be somehow "timeboxed". The final software application is planned to be delivered after 6 iterations, of the 6 discrete stages specified above. A stage-specific development team executes the activities at the corresponding stage following the sequence of iterations. All stage dependencies are finish-to-start (FS), as shown in the precedence network diagram on the left of Figure 2 along with the most likely estimate of the duration of each stage at each of the 6 iterations. The network also depicts precedence constraints between stages within iterations (e.g., Use-Cases Analysis and Requirements Review stages take place in parallel after Domain Modelling is completed).

Although the initial objective was to keep project management complexities as low as possible, the resulting PERT diagram for all six iterations portrays a multiplicative complexity for the whole project (Figure 2). The critical path of the entire project consists of stages A and C in iteration 1, the sequence of stage E in all iterations, and stage F in iteration 6.

4.1 CPM ES & LS Schedules

The schedule produced from the Critical Path Early Start Method (CPM ES) minimizes the project duration and, at the same time, the completion time (the release time for software parts) in all iterations. In general, obtaining a partial software delivery as early as possible could affect negatively the software quality but positively the financial performance of the project, in cases where customer payments are contingent upon partial deliveries. In such a case, the objective must be set to minimizing the completion time of all or certain iterations (that is to minimize as much as possible the time boxes of iterations), even if work continuity is sacrificed. Note that an iteration completion time denotes a lower bound for the corresponding time box.

Setting the objective function as in Eq. 9 the LP solution coincides with the CPM ES schedule which yields for the project example a duration equal to 48 working days, with iteration completion times and work-breaks set as shown in Figure 3. In the corresponding linear scheduling diagram, the progress of each stage through the project iterations is represented by a piecewise straight line. The slope of the line corresponds to the production rate of the specific stage at each iteration. Horizontal segments

on the progress line correspond to work-breaks (i.e., work interruption) between the execution of the same stage in successive iterations. Vertical segments represent specific cases, where a stage is not included in the corresponding iteration.

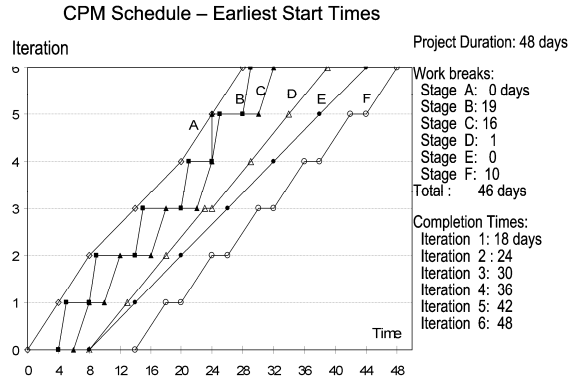


Figure 3: Linear scheduling (CPM - ES).

CPM is insufficient in addressing work continuity objectives and, consequently, does not consider utilization levels of development teams. Work-breaks cannot be eliminated or even reduced by scheduling stages according to the Latest Start (LS) time, as it is demonstrated in Figure 4.

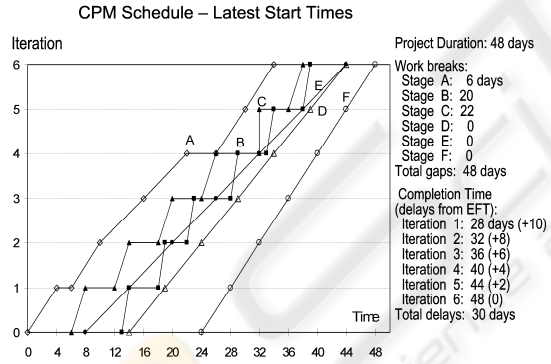


Figure 4: Linear Scheduling (CPM - LS).

Pushing stages to their LS time moves work-breaks from the last project stages to those in the beginning. In the specific project example, the LS schedule introduces even more work-breaks, while, at the same time, produces delays in intermediate/partial deliveries (i.e., timebox violations). Additionally, the LS schedule fails to address planning for agility aspects (Rosenberg *et al.* 2005), since it consumes all the "slack time" for teams performing the stages, hence making the project performance more vulnerable to unexpected delays/interrupts (e.g., major design errors, changes in user requirements etc.).

4.2 Minimizing Work-Break Time

Setting the 48 days CPM duration as the constraint of Eq. 4 (UC_6=48), and selecting the objective function of Eq. 8, the LP model produces a schedule that minimizes the total resource work-break time, while maintaining the overall project completion time as set by the CPM schedule. The resulting schedule for the project is shown in Figure 5. The minimum project duration of 48 days can be achieved with a minimum of 26 days of work-breaks concentrated at stages B and C. Further reduction of stages work-break time cannot be achieved without extending the project duration beyond 48 days.

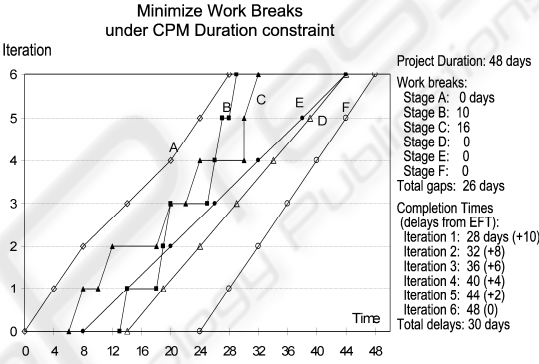


Figure 5: Minimization of work-breaks under CPM duration.

If the CPM duration constraint is relaxed, work-breaks can be further reduced to a minimum of 5 days, causing however a delay in the delivery of the project, the duration of which is extended from 48 to 64 days, as depicted in Figure 6.

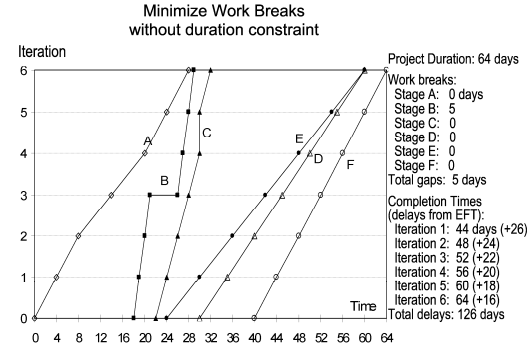


Figure 6: Minimization of work-breaks without duration constraints.

The work-break at stage C is eliminated, while at stage B is reduced to 5 days. The completion time of all iterations is also pulled to 16 days later than in the previous schedule. A saving of 21 days in work-

breaks is traded-off with a project delivery delay of 16 days. In the next section, trade-off issues between work-breaks and software parts delivery/release times are further investigated by using LP sensitivity analysis.

5 TRADE-OFF ANALYSIS

All schedules derived under the previous conditions were based on a single criterion each time. Alternative schedules optimized with respect the different evaluation criteria as they are defined in Eqs. 7-11, can also be easily derived by the LP model. The objective function defined in Eq. 12 consolidates the criteria of project duration, iteration completion time/time box duration (release time of each software part), and work-break into a single composite criterion. A necessary condition is to estimate the relative unit cost of each of the above project parameters.

Work-break costs may vary among different stages, according to the effort and scarceness of the resources (team members) involved in each stage. The same holds true with the cost associated with delays in completion/delivery time of different iterations (i.e., the cost of violating timebox constraints) which can affect the overall cost of the project, either directly (i.e., delay penalties) or indirectly (i.e., financial cost due to late cash receipts or delays in revenue generation). However, the sensitivity analysis results on the parameters of the objective function of Eq. 12 can be used to establish optimum schedules at different levels of cost relations, with no need to have accurate estimates of the exact cost, as it is demonstrated in the following two examples.

5.1 Trade-off between Project Duration Delay and Work-Breaks

The first example demonstrates a trade-off analysis between the cost of delays in project completion and that of work-breaks. Delays are measured in time units as deviations from the earliest finish date of the project as it is set by the CPM or from any predefined delivery date set by the project manager and/or the final user. It is also assumed that intermediate delays in completing individual project iterations do not impose any additional cost to the project, and that the cost of work-breaks is the same for all stages. In this case, the objective function (Eq. 12) of the model is equivalent to:

Minimize $c(UC_N) + f(WB)$ or

$$\text{Minimize } c\{UC_N + (f/c)WB\} \quad (13)$$

where c and f denote the daily cost of project delay and work-break, respectively.

The results of the sensitivity analysis on the values of the coefficient f/c of the objective function in Eq. 13 set optimality ranges, associated with alternative optimum schedules as shown in Figure 7. For the specific project example three optimality ranges are identified: When the work-break unit cost ranges between zero and up to 50% of the delay cost (Range I), the optimum scheduling results in project duration of 48 days (minimum possible) with a maximum work-break time of 26 days. When the work-break unit cost ranges between 50% to 100% of the delay cost (Range II), it is more economical to let the project duration slip by 5 days in order to gain a reduction of 16 days in work-breaks. Finally, when the work-break cost exceeds the lateness cost (Range III), the optimum schedule is the one that reduces work-breaks to the minimum of 5 days, which results in extending the project duration by 16 days.

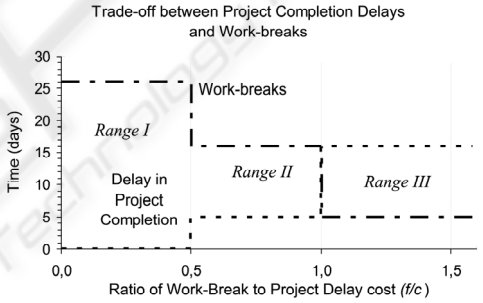


Figure 7: Trade-off between project completion delays and work-breaks.

5.2 Trade-off between Iteration Completion Delays and Work-Breaks

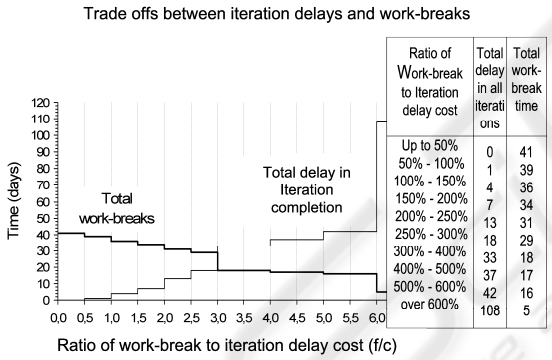
In the second example, we examine the scenario where a penalty cost is associated with delivery delays in the completion of individual project iterations. Delivery delays/time box violations could be measured as deviations from the earliest finish dates of the project iterations (Figure 3) or from a promised time box specified by the project manager and/or the customer for each software release. The choice does not affect at all the range analysis that follow, since the cost coefficients of the objective function remain unchanged. For simplicity purposes we assume that the same penalty applies to delays in any timeboxed iteration. Also, as in the previous

case, the cost of work-breaks is assumed to be the same for all stages. In this case, the objective function (Eq. 12) of the LP model can be written as:

$$\text{Minimize} \sum_{j=1}^{N} c_j.(UC_j - D_j) + \sum_{i=1}^{M} f_i.WB_i \text{ or}$$

$$\text{Minimize } c\left\{\sum_{j=1}^{N} UC_j + \left(f/c\right)\sum_{i=1}^{M} WB_i\right\} - c\sum_{j=1}^{N} D_j \quad (14)$$

Since the second part of Eq.14 is constant, the analysis to define ranges of optimality is based on the level of the *f/c* ratio. The results shown in Figure 8 indicate 10 optimality ranges corresponding to 10 different optimum solutions, according to the relation of the work-break to the iteration completion cost. A schedule which minimizes the work-break time (5 days) is optimum only when the associated work-break cost is at least 6 times the cost paid for iteration delays, and it is achieved by introducing a total of 108 days of delay in the completion of all iterations. As the relative size of the work-break to iteration delay cost drops, alternative solutions that allow for work-breaks may be more cost efficient.



Ratio of Work-break to Iteration delay cost	Total delay in all iterations	Total work-break time
Up to 50%	0	41
50% - 100%	1	39
100% - 150%	4	36
150% - 200%	7	34
200% - 250%	13	31
250% - 300%	18	29
300% - 400%	33	18
400% - 500%	37	17
500% - 600%	42	16
over 600%	108	5

Figure 8: Trade-off between iteration completion delays and work-breaks.

A notable break point in optimality conditions occurs at the point where work-break cost is 3 times the cost of delays. Under this level total delays in the iterations are kept below 18 days in total (average 3 days per iteration) while above it, delays range from 33 to 108 days (about 5,5 to 18 days per iteration). Figure 8 gives a graphical representation of the results. Any distinct segment of a cost coefficient ratio defined by the sensitivity analysis, corresponds to an optimal schedule associated with specific project duration, delays in iteration completion and work-breaks. The number of alternative optimum solutions, the trade-off brake points and levels depend on the constraints of the specific problem that define the set of all feasible schedules.

6 CONCLUSIONS

Project scheduling in iterative software projects which employ a timeboxing process model is generally not a single dimension decision process. A scheduling decision should take into account more than a single factor and, most of the times, trade-offs are required between iteration completion times (violations of time boxes), project duration and work-breaks for teams working in the same stages in successive project iterations. In this paper, we proposed a multi objective linear programming model to address these issues and overcome some simplifications of conventional timeboxing. In the proposed model, the planning duration of iterations is not a priori fixed, the durations of each stage in each respective time box may be not equal, precedence constraints between stages in each iteration are not simple sequential relationships, and, finally, it is possible to consider a wider range of software projects, where work discontinuities exist between stages in successive iterations. The model has the capacity to provide optimum schedules for iterative projects which follow timeboxing disciplines, reflecting not only single but multiple objectives and assists software project managers in selecting among alternative schedules based on the relative magnitude of different cost elements. In this sense, the presented model provides software managers with the capability to consider alternative schedules besides those defined by minimum duration or minimum work-break criterion.

A fully integrated software implementation of the proposed approach in a model-based environment that supports the graphical representation of software development processes and the process managerial analysis as well (Gerogiannis *et al.*, 2006) will enhance its applicability to real-world software projects. Although the model implementation, as it stands, can handle the problem formulation of various types of timing constraints, there are other issues that need further research. One such issue is the formal modeling of developers' learning curves (Hanakawa *et al.*, 2002) to consider measures of software productivity and estimates for projects progress. Another research area that we plan to consider is the risk level associated with the alternative scheduling decisions, as it is indicated by the slack time of the iteration stages and the probability of meeting the objectives set (software delivery times, work-breaks, etc.), since unexpected events in one stage or iteration (e.g., major changes in user requirements) may affect not only the duration of the project and

the iteration completion/delivery times but also the work continuity in project resources. Similarly, the use of simulation techniques could provide further insight on the stability of the alternative optimum solutions defined by the trade-off approach.

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