Proceedings of the 2011 Winter Simulation Conference
S. Jain, R.R. Creasey, J. Himmelspach, K.P. White, and M. Fu, eds.

A SIMULATION-BASED APPROACH TO ENHANCING PROJECT SCHEDULES BY THE INCLUSION OF REMEDIAL ACTION SCENARIOS

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ABSTRACT

Project schedules are typically defined in relatively strict terms and often rely on well-defined task ordering. Commonly, each task has either a pre-determined duration, or, a minimum, a maximum and a most-likely duration length. In real-life, however, projects are subject to numerous uncertainties. They often impact durations of tasks and may lead to project re-scheduling. In such cases managers need to decide about some remedial action scenario (RAS) to limit the impact of uncertainty on the overall project success. They are usually left clueless on what the most appropriate action to take is. To solve this problem, we propose a novel approach to enhance project schedules by the inclusion of an optimal RAS to be followed when uncertainties occur. This defines the *enhanced project schedule* model. The particular RAS, modeled by a set of fuzzy rules and selected using proxel-based simulation, becomes an integral part of the enhanced project schedule.

1 INTRODUCTION

Nowadays, it is well-recognized that the success of projects is directly related to their *project management* (Herroelen 2005). Project management is the discipline of planning, organizing, and managing resources to achieve the specific project goals and objectives. It is the activity which uses the schedules to plan and subsequently report progress within the project environment. Initial project plans are usually concerned with defining the project mission, developing project schedule plans, client consultation and client acceptance (Pinto 2002). They are also used as a basis on which to make delivery commitments to clients, hence the importance of constructing a credible plan that provides a good estimation of the completion dates.

Many approaches have been conducted with the goal of generating better project schedules (Herroelen and Leus 2005; Arauzo et al. 2009; Huang et al. 2009; Jing-wen and Hui-fang 2009; Sobel et al. 2009). They are based on various techniques and each of them endeavors to offer an optimal schedule. Simulation is one of the techniques that have been successfully applied to project planning. However, because of the interrelated natures of project factors, developed schedule models often suffer from many limitations that make them not representative to real world situations. Typically, project schedules are described in very strict terms, using Gantt charts. Each task has a pre-determined duration, or in the most-flexible scenario, has a minimum, a maximum and a most-likely duration.

In real-life often things do not run as planned and projects are subjects to numerous uncertainties. These uncertainties affect the duration and the cost of the project. A simple example for this would be a delay in the completion time of a certain task. When this happens, it is obvious that the next task on the list of responsibilities of the corresponding team will not begin on time. In such a case, the project manager may take one of the several actions, such as:

(1) allocate a new team to implement the task, which may consequently affect the rest of the tasks;
(2) wait until the concerned team becomes available; or
(3) postpone the task implementation.

Apparently, each of these decisions may affect the project delivery date, but not necessarily in the same way. Managers are, typically, left clueless as to what remedial actions to take to minimize the negative effects of unpredicted events on project's goals and deadlines.

Until now, the major project schedule software packages such as Microsoft Project, are too stiff in defining project schedules. In addition, many of the existing analysis methods and tools oversimplify the uncertainty in projects and thus provide less accurate results and schedules (Huang et al. 2009; Navascués et al. 2009; Sobel et al. 2009).

To increase its effectiveness and, at the same time, provide realistic definition and analysis, a project schedule has to accommodate a high degree of uncertainty and offer recommendations to aid the decision making processes in various predictable uncertain scenarios. This implies that the schedule itself should guide the decisions about the best remedial actions to be taken to minimize the deviation from project's ultimate goals. Therefore, we propose that project schedules are described in a way that allows their adaptation as new information becomes available. To achieve this goal, we have implemented modifications on the basic project schedule model.

To summarize, our purpose is to help the generation of *a more realistic and insightful* planning. The challenges we target to answer are:

1) How can an initial project plan be more insightful and more realistic?;
2) How can an initial project plan simulation help managers in better assessing risks associated with their decisions when uncertainties arise?; and finally,
3) What changes should be made to incorporate these remedial action scenarios to the simulation model to make it more flexible?

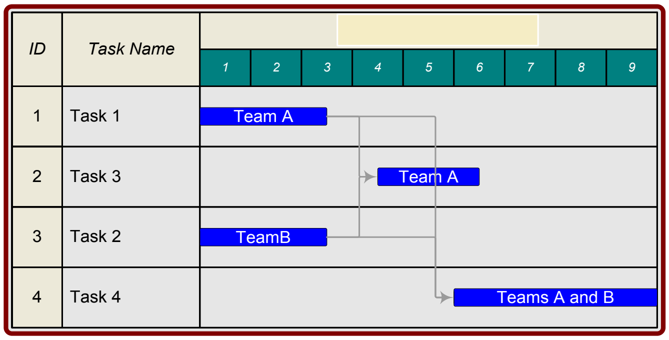
Figure 1(a) illustrates a simple project schedule, modeled using a classical Gantt chart. The project schedule consists of four tasks (*Task1*, *Task2*, *Task3*, and *Task4*) and two available teams (*Team A* and *Team B*). All tasks have predefined executors leading to one possible scenario of execution. Such model is in fact rigid and it is not able to anticipate the occurrence of any unpredictable event.

Figure 1(b) illustrates the enhanced project schedule that we propose. While having the same number of tasks and teams, two majors features are added:

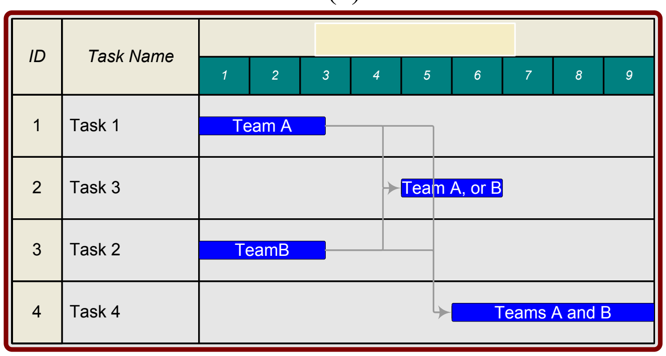
1) a "*floating task*" (*Task 2*), which is a non-vital task that can be executed by any of the two teams, albeit with different duration distribution functions based on teams' expertise.
2) a *remedial action scenario* (RAS), provided on the right-hand side, which is meant to accompany the project schedule as a set of recommendations during its implementation. This RAS suggests that depending on the durations of *Task2* and *Task4*, *Task3* is may be cancelled. This is an example of changing the sequencing, once more information is available.

In our previous work (Lazarova-Molnar and Mizouni 2010; Lazarova-Molnar and Mizouni 2010) we were able to successfully model and simulate the type of schedules described in Figure 1(b). We developed an approach to analyze and simulate the effects of the uncertainties and remedial actions on the duration of a project. To account for resource re-allocations we have also defined a new type of task, which we termed as "floating task". This task is typically a non-crucial task for the success of the project and could be implemented by a number of teams, albeit with different duration distribution functions, and based on their availabilities. During this work, we showed that the modeling of the *on-the-fly* decisions makes a significant difference in the prediction of the duration of the project and consequently needs to be considered.

(a) No additional rules



(b)



Example of guidelines that create one remedial action scenario:

1. If duration of task T2 performed by team B is "very short" then start T3 by team B.
2. If duration of T1 is "too long" and it completes "shortly after" team B started to work on T3, then T3 is cancelled and both teams start working on T4.

Figure 1: Illustration of: a) Classical Project Scheduling based on Gantt Chart and b) Enhanced Project Scheduling Based on Gantt Chart and RAS

Enhanced project schedules, defined in the afore-described way are flexible and allow for a high degree of beneficial interventions, as opposed to the rigid ones that are traditionally described by Gantt charts and handed to project managers.

Remedial action scenarios are modeled using *fuzzy rules*. A strong argument for using fuzzy rules is the solid theory of the straightforward conversion of linguistic expressions into fuzzy membership functions (Zadeh 1975). Our approach will invite experts to spend more time thinking, analyzing and using historical data to set the parameters in the model. E.g., our approach asks for estimation of task duration probability distribution functions for each team that is capable of performing it, thus leaving open possibilities for variable task executors and task sequences; an important factor in designing the remedial action scenarios. Basically, the process of defining an enhanced project schedule assures a careful and high-quality initial planning, thus reducing the risk in the project. To summarize, in this paper, we propose to use the enhanced project scheduling to assess different possible remedial action scenarios the manager can consider in case of uncertainties. The result of the simulation will guide the choice of the manager to better fulfill project goals.

2 SUITABILITY OF THE PROXEL-BASED METHOD FOR SIMULATION OF THE ENHANCED PROJECT SCHEDULES

The proxel-based simulation method is our method of choice for the analysis of the enhanced project schedules. Our decision was based on the flexibility and accuracy of the method that allowed us to easily incorporate the fuzzy rules within the existing method's framework.

The proxel-based method is a simulation method based on the method of supplementary variables (Cox 1955). It was introduced and formalized in (Horton 2002; Lazarova-Molnar 2005). The advantages of the proxel-based method are its flexibility to analyze stochastic models that can have complex dependencies and at the accuracy of results, which is comparable to the accuracy of Markov chain numerical solvers (Stewart 1994).

The proxel-based method is based on expanding the definition of a state by including additional parameters which trace the relevant quantities in one model through a previously chosen time step. Typically this includes, but is not limited to, age intensities of the relevant transitions. The expansion implies that all parameters pertinent for calculating probabilities for future development of a model are identified and included in the state definition of the model.

Proxels (stands for probability elements), as basic computational units of the algorithm, follow dynamically all possible expansions of one model. The state-space of the model is built on-the-fly, as illustrated in Figure 2, by observing every possible transiting state and assigning a probability value to it (*Pr* in the figure stands for the probability value of the proxel). The state space is built by observing all possible options of what can happen at the next time step. The first option for the model is to transit to another discrete state in the next time step, according to the associated transitions. The second option is that the model stays in the same discrete state, which results in a new proxel too. Zero-probability states are not stored and, as a result, no further investigated. Consequently, only the truly reachable (i.e. tangible) states of the model are stored and expanded. At the end of a proxel-based simulation run, a transient solution is obtained which outlines the probability of every state at every point in time, as discretized through the chosen size of the time step. It is important to notice that one source of error of the proxel-based method comes from the assumption that the model makes at most one state change within one time step. This error is elaborated in (Lazarova-Molnar 2005).

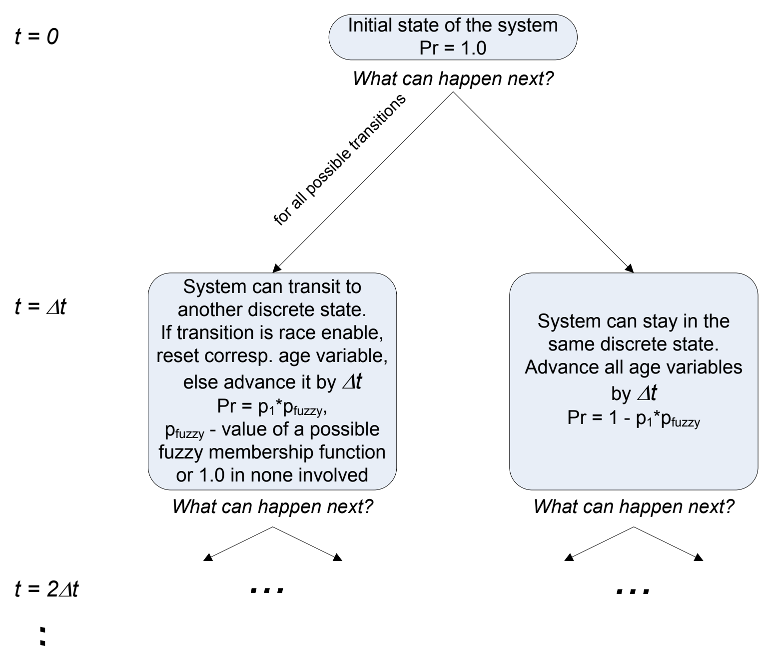


Figure 2: Illustration of the development of the proxel-based simulation algorithm

Each proxel carries the probability of the state that it describes (in Figure 2 denoted as *Pr*). Probabilities are calculated using the instantaneous rate function (IRF), also known as hazard rate function. The IRF approximates the probability that an event will happen within a predetermined elementary time step, given that it has been pending for a certain amount of time τ (indicated as 'age intensity'). It is calculated from the probability density function (*f*) and the cumulative distribution function (*F*) using the following formula:

$$\mu(\tau) = \frac{f(\tau)}{1 - F(\tau)} \tag{1}$$

As all state-space based methods, this method also suffers from the state-space explosion problem (Lin, Chu et al. 1987), but it can be predicted and controlled by calculating the lifetimes of discrete states in the model. In addition, its efficiency and accuracy can be further improved by employing discrete phases and extrapolation of solutions (Isensee and Horton 2005). More on the proxel-based method can be found in (Lazarova-Molnar 2005).

For our purpose we extended the original proxel-based simulation algorithm to account for the RAS (shown by the p_{fuzzy} variable in Figure 2). They fitted straightforwardly into the existing framework. The proxel-based simulation can answer a number of questions, such as:

a) What is the overall duration of the project?, or

b) What is the probability that the project is completed before a certain deadline?

The relevant statistics are collected by introducing rewards and their adequate manipulation. They are introduced as rewards associated with the completions of tasks. They allow a probabilistic assessment of the completion of a task, subject to the RAS associated with the project schedule. Finally, the results obtained are probability functions of time that show the probabilities of having each task completed.

3 ENHANCED PROJECT SCHEDULING USING FUZZY RULES

We propose the definition of a schedule to include the possible uncertainties that can arise and quantify those using statistical probability distributions. In addition to this, we propose formalizing the remedial actions that managers can consider. Every schedule along with the set of remedial actions (RAS) creates, what we term as: *enhanced project schedule.* Formally, each project schedule consists of two components: initial Gantt chart and a remedial action scenario, as shown in Figure 3. The RAS consists of a set of fuzzy *if-then* production rules. These rules make the project evolving and thus, the sequencing of tasks, dynamic and changing.

Let us take the example of a simple software development project schedule, subject to various uncertainties. The enhanced schedule would consist of a Gantt chart, where each task that corresponds to a requirement implementation, is associated with a probability distribution function for its duration, as well as a set of fuzzy rules (or RAS) that describe the remedial strategy under certain conditions (e. g. if task A finishes in a very short time than proceed to task B, else skip task B). The set of fuzzily specified guidelines are obtained by simulating a set of possible RAS, and accordingly selecting the most optimal one (similar to the simple example presented in Figure 1(b)).

Figure 4 shows our simulation approach. Once the enhanced project schedule is designed, we simulate each RAS using the proxel-based method and pick the best one based on the success criteria for the project (project goal). The probability that the project is delivered before deadline is an example of a success criteria. However, in another case, the budget may play a more important role, or, more often, it might be both.

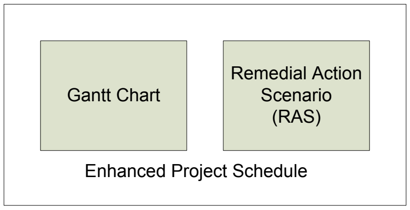


Figure 3: EPS Components

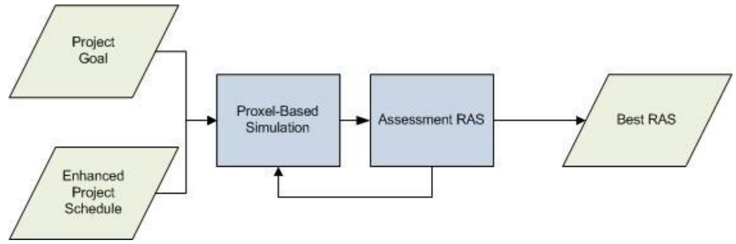


Figure 4:Simulation Approach

Once the simulation of the chosen RAS provides good results with respect to project goals (i.e. complete as many tasks as possible, complete in as short time as possible, or minimize budget), it can be communicated to the project manager to aid his/her decision making process. We see the fuzziness as a great advantage as it leaves a certain degree of freedom to the project manager as well, to involve his/her knowledge/perceptions he/she might have.

The proxel-based simulation method allows for a great flexibility in schedules and provides solutions with regards to all anticipated uncertainties. This helps us in picking the best RAS that specify the best recommended remedial actions when uncertainties occur.

3.1 Model Description

Each Enhanced Project Schedule (EPS) is described in the following way:

$$EPS = (A, P, T, D, W, F, IGC), \text{ where}$$

- $A = \{A_1, A_2, \dots, A_n\}$, set of tasks, where each task corresponds to a task in the project schedule
- $P = \{P_1, P_2, \dots, P_m\}$, set of precedence constraints, that are actually tuples of two tasks where the completion of the first one is a pre-requirement for commencing the second one, e.g. (A_x, A_y) would mean that completing of A_x is a pre-requirement for beginning A_y
- $T = \{T_1, T_2, \dots, T_l\}$, set of teams available for the execution of the project
- $D = \{d_1, d_2, \dots, d_s\}$, set of probability distribution functions that correspond to duration of tasks performed by the competent teams
- $W = \{w_1, w_2, \dots, w_t\}$, set of mappings of distribution functions to competent teams and tasks
- $F = \{f_1, f_2, \dots, f_s\}$, set of fuzzy rules that define the remedial action scenario
- $IGC - Initial\ Gantt\ Chart$, initial sequencing of tasks that satisfies the set of precedence constraints provided by P

and where $P \subseteq A \times A$, and $W \subseteq A \times M \times D$. Also, $A = A^c \cup A^n$, where A^c is the set of cancelable tasks and A^n is the set of non-cancelable tasks. Cancelable task is a task that is non-vital for the success of the project, and thus, not compulsory, however, useful for the value of the project. Non-cancelable tasks are the ones that are crucial for the success of the project. This differentiation is important for the realistic simulation of project schedules.

Each fuzzy rule is made up of two parts: *condition* and *action*, formally expressed as "$condition \Longrightarrow action$". Conditions can be described either by using strict terms, or fuzzy ones. An action can typically be canceling or interrupting some of the tasks, or one of the various types of rescheduling. This is the fact that makes our schedule description evolving, rather than rigid and inflexible. Two examples of fuzzy rules are:

$$A_x \, takes \; too \; long \Rightarrow cancel \; A_y$$

or

$$A_x \, completes \; quickly \; after \; A_y \Rightarrow cancel \; A_z.$$

Both are examples for typical proceedings during project execution. However, in our approach we allow for their modeling, assessment and quantitative evaluation. This makes it straightforward to study the tradeoffs between the various RAS and test for the best possible RAS to balance the uncertainties, as described by F. Note that F can be an empty set too, which would imply sticking to the original project schedule provided by IGC. Once such remedial action scenario is provided, it is associated to the project schedule and handed to the project manager as a decision making aid. This is further demonstrated by a simple example in the following section.

4 EXPERIMENTS

We consider a general example of a project schedule that contains 4 tasks, identified as: Task 1, Task 2, Task 3, and Task 4. Tasks can be performed by one of the two teams, as predetermined: Team A and Team B, albeit tasks 1, 2 and 3 have fixed human resource allocation, i.e. performing team and task 4 is a *cancelable floating task*, and can be performed by either team A or B. The initial Gantt chart (*IGC*) of the sample project schedule is shown in Figure 4, where the green-colored tasks are cancelable and the team capable of carrying out task is labeled on the task itself. In addition to this the project schedule has a predefined deadline Δ.

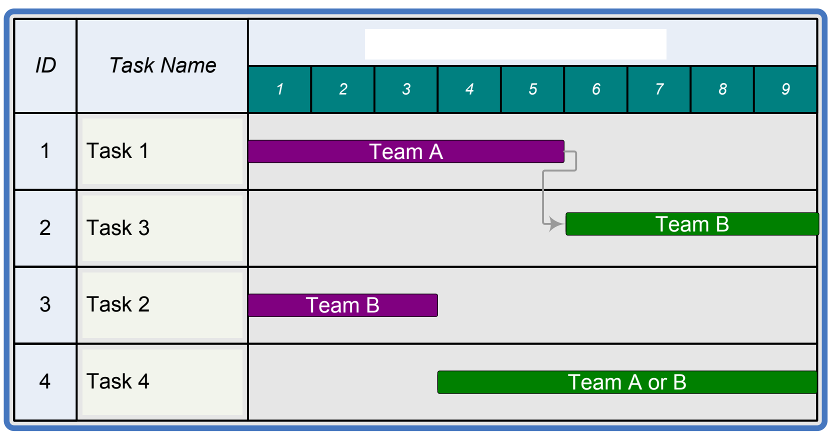


Figure 5: Initial Gantt chart of the example project schedule (the green-colored tasks are cancelable)

The model that we are using to present our approach consists of three types of tasks:

- non-cancelable, non-floating (rigid): Tasks 1 and 2,
- cancelable, non-floating: Task 3, and
- cancelable, floating: Task 4.

Apparently, the last two categories (the cancelable tasks) are the ones that represent the "useful" requirements, i.e. the features that are "nice to have" but not compulsory for the functionality of the final product.

The project schedule is described as an enhanced project schedule, which means it also features a RAS, under which conditions it is observed. The RAS enhances the degree of consideration of the uncertainty and creates a dynamic project schedule, based on an initial one.

In our case the three remedial action scenarios are defined as follows:

a) *<u>RAS (a):</u> If the duration of tasks 1 or 2 is close to the deadline Δ, then do not start working on any of the tasks 3 or 4 and do not interrupt the other team if they have already started to work on either of the latter two tasks.*

b) *<u>RAS (b):</u> If the team assigned to a certain task (Task 3 in our case) is unavailable then cancel the task.*

c) *<u>RAS (c):</u> No guidelines are provided and the manager is instructed to follow the original schedule.*

For all three RAS we will calculate the following performance measures:

- the probability of completing the project before the deadline, and
- the number of tasks completed before the deadline (since some tasks may be canceled).

Our goal is to decide which of the RAS yields the best performance, given the constraints of the initial project schedule. For this purpose we run proxel-based simulation which allows us to collect the necessary statistics to answer our question.

For illustration, the state-space of our model for the RAS (a) is shown in Figure 5. The red arrows represent state-transitions that occur as a result of the evaluation to true of the "close to the deadline" fuzzy function. Each state is represented by the tasks that the two teams work on currently, as well as the set of completed tasks (*I* stands for Idle), e.g. $(T4,T3)_{T1,T2}$ means that team A is working on Task 4, team B is working on Task 3, and both Task 1 and Task 2 have been completed.

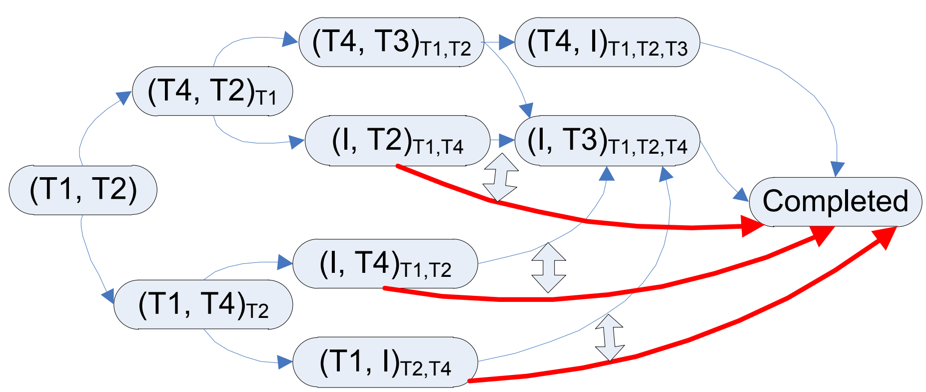


Figure 6: State-space of the project schedule model from

Figure 5, considered under RAS (a)

The concrete parameters of our model, used in the experiments, are as follows:

- Duration of Task 1 ~ Uniform (2.0, 10.0)
- Duration of Task 2 ~ Normal (7.0, 1.0)
- Duration of Task 3 ~ Uniform (2.0, 8.0)

- Duration of Task 4, performed by:
  - Team A ~ Weibull (3.5, 1.5)
  - Team B ~ Uniform (2.0, 5.0)

The fuzzy membership function that describes *close to deadline* is defined as follows:

$$\mu(t,a,b)=\begin{cases}0, & t<a\\ \dfrac{t-a}{b-a}, & a\le t\le b\\ 1, & t>b\end{cases}, \text{ where } a=\Delta-\frac{\Delta}{4}, b=\Delta.$$

In our concrete case, as Δ = 15, thus the concrete fuzzy membership function is $\mu(t,11.25,15.0)$.

4.1 Experimental Results

In the following we present the results of the simulation of our model. The proxel-based simulation provides complete results for any quantity of interest, in this case it is the probability function of the duration of the project (shown in
Figure **7**) and the probability function of having all four tasks completed (shown in Figure 8). The measures are not limited to this and these two are provided for illustration only. In general, they can include any quantities that are relevant to project's goals.

The simulation results will provide us with an overview to aid the selection of the most suitable remedial action scenario with respect to project's goals.

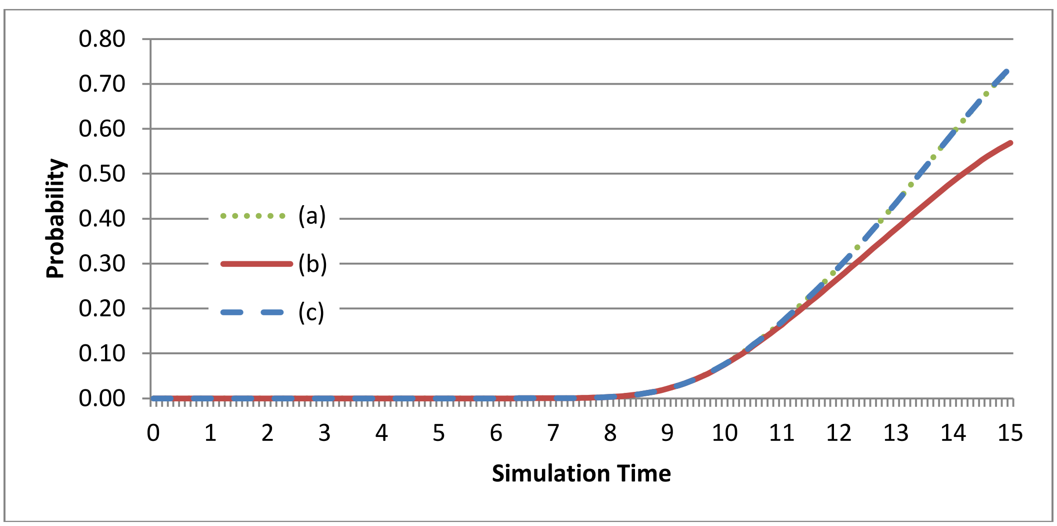


Figure 7: Probability of having all four tasks of the project completed for the three possible RAS

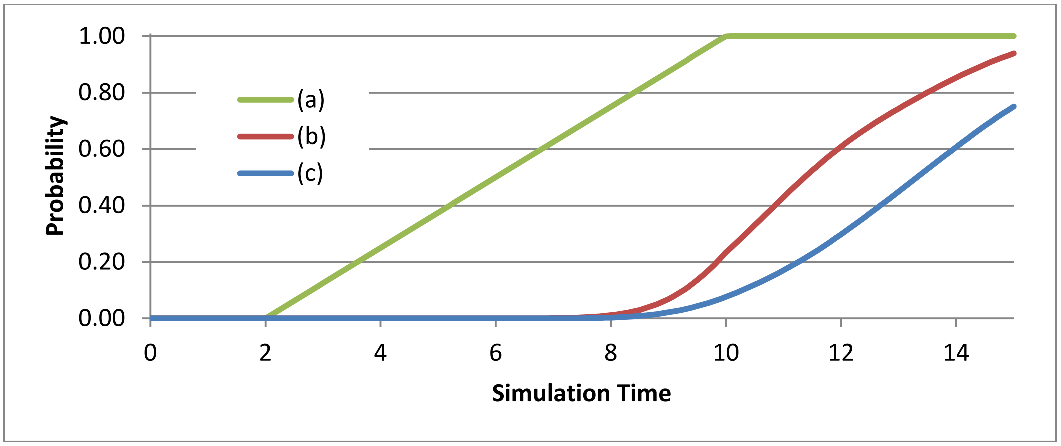


Figure 8: Probability of having the project completed for the three possible RAS

From the simulation results we can see that the best RAS that yields the highest probability of having the project completed before the deadline is RAS (a), closely followed by (b). However, in terms of the number of tasks completed, RAS (a) and (c) have the highest probability of having all tasks completed before the deadline. Judging from this, we can conclude that the RAS (a) seems most favorable for this project schedule. Also, we can clearly see that the rigid RAS (c) which does not allow for any changes has the lowest probability of having the project completed before the deadline.

5 SUMMARY AND OUTLOOK

In this paper we present a novel simulation-based approach to defining project schedules, such that they can also serve as guides when uncertainties appear and provide recommendations to project managers to support their decision making processes. Decisions made in this way, will not be solely based on human judgment, as the usual approach is, but also based on sound models and methodologies.

We believe that this is a much more effective way of designing schedules and that it exceeds classical project schedules by allowing all available information to be utilized. Instead of having a static schedule, the inclusion of remedial action scenarios makes enhanced project schedules dynamic and evolving. This corresponds much better to real-world project implementation developments.

Our model and approach can be further enhanced to allow for project schedule simulations to commence at any point in time during the project and thus provide real-time analysis. This will improve the accuracy of predictions, as later during project implementation, some uncertainties are not uncertain anymore due to the fact that the project has already taken directions.

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