Schedule risk assesment in planning ship production

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This paper presents a risk assessment approach for evaluating the goodness of ship production scheduling and planning. The objective of this paper is to utilize the probabilistic analysis to assess the goodness of the proposed planning of ship production in shipyards. The approach is based on the uncertainty propagation analysis of the scheduling parameters and resources. The impact of the analysis on the risk of non-completing the shipbuilding process on time is calculated. The impact of uncertainty characteristics such as mean value and standard deviation on the risk is investigated. The impact of crucial tasks time and crashing techniques on the risk involved in scheduling is assessed. Critical Path Method (CPM), and Program Evaluation and Review Technique (PERT) are the main techniques used in the calculations. Further work is needed to include cost risk into the schedule risk to assess integrated risk involved in engineering project management.

يقدم هذا البحث طريقه لتقييم جودة تخطيط إنتاج السفن على أساس حساب المخاطر فى الجدولة الزمنيه لمشروع إنهاء بناء السفينه. فى هذا البحث, تم استخدام مثال مجمع فى سفينه لحساب المخاطر الموجوده نتيجة عدم اليقين من زمن كل عنصر من عناصر عملية بناء المجمع ولإظهار تأثير السيطره على المخاطر فى تخطيط الجدولة الزمنيه للمشروع على إنهاء المشروع فى الموعد المحدد. تم دراسة تأثير المهام المؤثره فى بناء المجمع على المخاطر فى الجدولة الزمنيه للمشروع. تم استخدام طريقتا المسار الحرج ومراجعة وتقييم الخطط لإنجاز الحسابات. تم التوصيه بإدخال حساب المخاطر فى إقتصاديات المشروع وذلك لتكوين دراسة مخاطر كامله على أساس الإحتماليه للمشاريع الهندسيه.

Keywords: Project management, Ship building, Risk assessment, Gantt chart, CPM, PERT

1. Introduction

Completing a shipbuilding project on time is an essential part of implementing the building plan. A good project plan that is never implemented is no better than no plan. A task can be done in, say, two weeks - or one week if it is pushed, three weeks if bad circumstances occurred. Then time is added up to do the various tasks to estimate how long it should take to complete the project.

Managing schedule risk means arranging the project tasks and their resources (human and other) considering uncertainties involved in tasks duration in a sequence that facilitates their completion. In this paper, a simple case study of block assembly is presented to illustrate the impact of risk control during scheduling on the risk-involved in completing a project on time.

The management of ship construction requires the use of the related techniques of planning, scheduling, and production control. The productivity of the shipbuilding process is dependent on the coordination of different resources involved. Managing these resources is the key to efficient production.

Scheduling is the laying-out of the planned time in which tasks are to be performed. Material and manpower requirements needed at each stage of production are determined, as well as start and finish times for each job.

In defining planning and scheduling, the need to identify independent jobs or activities and an order of precedence for these jobs should be described. These data represent the prerequisites for employing the primary techniques of the Critical Path Method (CPM) or the Program Evaluation and Review Technique (PERT) [1].

PERT was first used in the 1950s on projects like the construction of the Polaris submarine - a project that required coordinating the activities of 250 contractors and 9000 subcontracts [2]. PERT requires task definition and duration in addition to the specification of the relationship between tasks and the resources required to complete each task in a given period of time. Once the network of activities is determined, the Critical Path

Method (CPM) is used to reallocate resources to find the shortest time in which the project can be completed (and what resources would be needed to do that).

The value of an engineering project will be degraded (or even completely lost) if the project cannot deliver the engineering products within the specified time frame. The great amount of uncertainties and variability involved in resources allocation can cause an unaccounted delay in the schedule, hence, economical losses, or even legal actions. The shipbuilding project planner should consider the uncertainty during scheduling. This paper will illustrate how to identify critical paths for schedule, evaluate uncertainties with the critical paths, and control the critical paths with risk management techniques.

2. CPM & PERT analysis

Tools for analyzing schedule risk require a few assumptions, and use only a few technical terms. PERT and CPM assume that all activities have distinct beginning and ending points. PERT and CPM assume that the estimates of the time needed can be well-defined mathematically. It takes a lot of experience to accurately gauge the time a task will take. Time estimates will be highly uncertain and the quantitative measures of "normal" time and the probability estimates of completion time will be highly unreliable .

Also, PERT and CPM assume that the time value of money is not an issue. In other words, there is no need to consider discounting of future costs (or benefits), nor are there indirect monetary benefits to time (other than those incorporated in the costs to "crash" the time). For most projects, these assumptions are acceptable.

The followings are a few technical terms used in PERT and CPM;

Critical path: the longest path (in terms of time) to the completion of a project, the critical path is the work-path, which, if shortened, would shorten the time it takes to complete the project. Activities off the critical path would not affect completion time even if they were done more quickly.

Slack time: Slack time is the difference between the expected time for arriving at the end of a task and the latest allowable time for finishing it.

Crashing: shifting resources to reduce slack time so the critical path is as short as possible.

2.1. PERT analysis

PERT was developed by the U.S. Navy for the planning and control of the Polaris Submarine missile program and the emphasis was on completing the program in the shortest possible time [2]. In addition PERT had the ability to cope with uncertain activity completion times (e.g., for a particular activity the most likely completion lime is 4 weeks but it could be anywhere between 2 weeks and 8 weeks).

1. Define tasks to be performed.
2. Link tasks in sequence.
3. Estimate time to complete each task (normal time) as follows;

• Use 3 estimates: most optimistic T_{oi}, the completion time we would expect under normal conditions, most pessimistic T_{pi}, the completion time if things go badly, and most likely T_i, the normal time.

• Determine the expected (average) time:

$$T = (T_{oi}+4T_i+T_{pi})/6. \quad (1)$$

Note that this weighting of the optimistic, most likely, and pessimistic times of 1/6, 4/6, 1/6 is fixed and cannot be altered (as the underlying theory depends on these weights).

4. Determine the standard deviation of meeting the expected time, use the time range (T_{pi}-T_{oi}) to estimate standard deviation of the time for each activity,

$$s_i = (T_{pi}-T_{oi})/6. \quad (2)$$

2.2. CPM analysis

CPM emphasizes on the trade-off between the cost of the project and its overall completion time; the followings are the steps needed to develop a CPM analysis for a project [1]:

1. Develop time and cost data (normal and crashed) for all tasks.

2. Develop cost-per-week for crashing (difference in cost divided by time saved).
3. Develop project network (PERT).
4. Accelerate the activity *on the critical path* with the lowest cost-for-accelerating.
5. Recalculate the project network (the critical path might have been changed).
6. Repeat steps 4 & 5 until all the paths have been minimized.
7. Ease up on all non-critical paths, just to the point that all paths are critical.

By assuming the distribution of completion times are normally distributed, and if the PERT analysis arrives at an expected completion time of 10 weeks and the standard deviation of that estimate (i.e.. the pooled standard deviations of the various tasks) is 1.0, then you can expect that 95% of the time (or, you can predict with 95% confidence) the project will be completed in 8-12 weeks. If you are more of a risk-taker, the confidence interval for ±1 standard deviation is about 68%.

3. Schedule risk for a block sub assembly task

Schedule risk assessment is the general name given to certain specific techniques, which can be used for the assessment, management and control of projects. As there are uncertainties in the estimation of the duration of the individual activities, the project completion time may be evaluated only with an associated uncertainty. We will illustrate schedule risk assessment with reference to the Block Sub assembly example. The following example of building a steel block (block 1-2) which consists of two subassemblies 1 and 2, each of which is made up of steel parts fabricated from plate, will be used to illustrate the risk due to uncertainties involved in undertaking tasks on time. The cited example is using assumed numbers for illustrative purpose only. The goal of this example is to demonstrate the impact of uncertainty in scheduling on the risk of completing the project on time.

Table 1 identifies the activities and their precedence relationships. Fig. 1 shows the developed Gantt chart (network) of the assembling process. The critical path is the longest path in a project network. In the example, the path 1,2,5,7,9,10 is the critical path, with project duration of 20 weeks.

The key question is: how long will it lake to complete this project? (i.e., complete all the activities while respecting the precedence relationships). One answer could be if we first do activity 1, then activity 2, then activity 3,..., then activity 10. Such an arrangement would be possible here (check the precedence relationships above), and the project would then take the sum of the activity completion times, or 20 weeks.

However, could we do the project in less time? It is clear that logically we need to amend our key question to be: What is the minimum possible time in which we can complete this project?

We shall see below how the network analysis (Gantt chart) we construct helps us to answer this question.

The second key question is: how certain are we that the project will be completed on time? In order to answer this question, we need to calculate the uncertainty characteristics in the completion time of the project due to uncertainty in completion time of each task.

In order to do this, we need to calculate the average and standard deviation of the completion time of the project. Then we can calculate the probability of failure of meeting the expected time of the project based on the assumption that the completion time follows a normal distribution. The normal distribution was assumed for simplification of the calculations. However, if more statistics are available on the uncertainty of undertaking of shipbuilding projects in shipyards, then the proper distribution type could be changed to Weibull, Lognormal, etc.

The critical path is found to be: 1-2-5-7-9-10. From table 1, the expected estimates for project completion time can be calculated by [3]:

Completion time = $T_1 + T_2 + T_5 + T_7 + T_9 + T_{10}$
= 3.25+7.58+1.08+5.42+1.08+3.25=20 weeks.

Table 1
Activities for building a steel block (block 1-2)

Task #	Activity name	Optimistic time (T_{oi}) weeks	Most likely time (T_{pi}) weeks	Pessimistic time (t_{pi}) weeks	Expected time= (T_{oi}+4T_i+ T_{pi})/6	St. Dev. s_i = (T_{pi}-T_{oi}) /6	Must be finished before this task starts	Variance (VAR)
1	Determining steel plate order	1.5	3	6	3.25	0.75	-	0.56
2	Shipping steel plate to shipyard	3.5	7	14	7.58	1.75	1	3.06
3	Preparing N/C tapes for cutting plate	4	8	16	8.67	2.00	-	4.00
4	Cutting parts for subassembly 1	0.5	1	2	1.08	0.25	2,3	0.06
5	Cutting parts for subassembly 2	0.5	1	2	1.08	0.25	2,3	0.06
6	Assembling subassembly 1	2.5	5	10	5.42	1.25	4	1.56
7	Assembling subassembly 2	2.5	5	10	5.42	1.25	5	1.56
8	Transporting subassembly 1 to block assembly site	0.5	1	2	1.08	0.25	6	0.06
9	Transporting subassembly 2 to block assembly site	0.5	1	2	1.08	0.25	7	0.06
10	Assembling Block 1-2	1.5	3	6	3.25	0.75	8,9	0.56

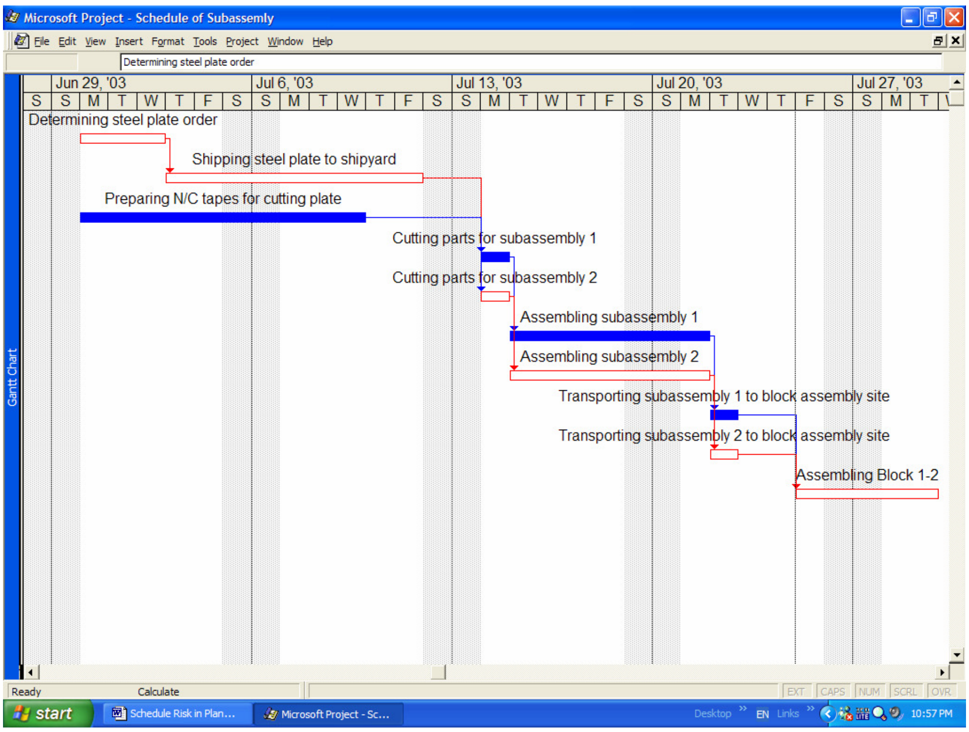

Fig. 1. Critical path in gantt chart of block assembly.

The standard deviation, a, can be calculated by [3];

$$\sigma = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_5^2 + \sigma_7^2 + \sigma_9^2 + \sigma_{10}^2}$$

$$= \sqrt{.75^2 + 1.75^2 + .75^2 + 1.25^2 + .25^2 + .75^2}$$
=2.42.

The following probability calculations assume that activities are independent and that all paths are also independent. It also assumes that there are a large number of activities so as to enable use of the normal distribution. Therefore, when the activities are not independent or the number of activities is not large, the analysis could be biased.

The probability of failure to meet the expected completion time is calculated by [3]:

$$P = 1.0 - \left\{ \Phi\left[\frac{(T-20)}{2.42} \right] \right\}, \quad (3)$$

Where *T* is the completion time of the task, and *F* is the standard normal cumulative distribution function. Eq. (3) gives the following values:
- Probability of finishing within 21 weeks is 0.66.
- Probability of finishing within 20 weeks is 0.50.
- Probability of finishing within 19 weeks is 0.34.

Using this probability analysis it is possible to construct the graph shown in fig. 2. For a range of possible project completion times, we have plotted the probability that the project will have not been completed by that time.

This plot is based on the assumption that one critical path is dominant. The analysis for multiple critical paths will be presented next.

4. Schedule risk for multiple critical paths

To obtain a better estimate of the schedule risk, the multiple work-paths and their impact on project schedule must obviously be included; nevertheless, the mutual correlation between the work-paths should also be considered.

Given n critical paths, the probability of not completing a project within specified time can be calculated as [3]:

$$P = 1 - (1-P_1)(1-P_2) \ldots (1-P_n), \quad (4)$$

Where P_i is the probability of not completing critical path *i* within specified time. Reducing an activity completion time is known as "crashing" the activity.

Suppose for the problem of assembling blocks, the specified completion time is 20 weeks: the probability of not completing the project is 50%: the management team feels that the schedule risk is too high given the importance of the project. The management team decided to crash the critical activity number 2 in order to reduce the length of the completing time of the project [4]; they shorten the duration of activity number 2 “Shipping steel plate to shipyard” to 5 weeks by arranging faster shipping process and increasing the margin of ordered amount of steel based on quick rough estimate of steel weight. This will result in an additional 5% cost of purchased steel [5]. The revised activity list and Gantt chart are shown in table 2 and fig. 3. It is also shown that crashing activity number 2 does not affect activity number 3 because the latter has a slack time of 2 weeks as shown in fig. 1.

As shown in fig. 3, there are two critical paths after incorporating the crash activity:
Critical path I: 1-2-5-7-9-10
Completion time = 18 weeks
Standard deviation = 2.09
Critical path II: 3-5-7-9-10
Completion time = 18 weeks
Standard deviation = 2.50

The probability of not completing project by time T can be calculated as [3]:

$$P = 1.0 - \left\{ \Phi\left[\frac{(T-18)}{2.09} \right] . \Phi\left[\frac{(T-18)}{2.5} \right] \right\}. \quad (5)$$

As shown in fig. 4, the probability of not completing the project within 20 weeks has been reduced to 21% by the crash activity in critical path II and to 17% in critical path I. It can be profitable to capture the benefits that

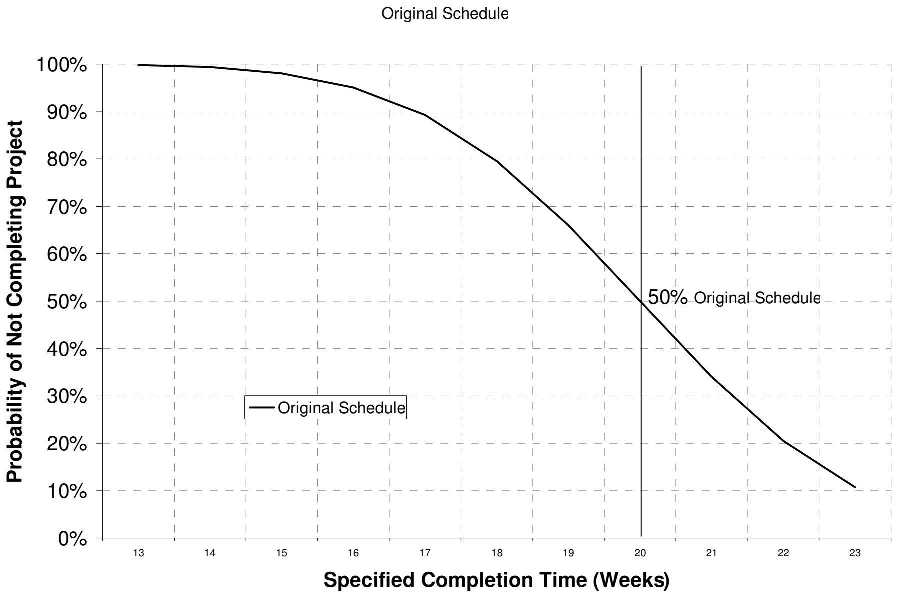

Fig. 2. Probability of not completing project within specified project completion time.

Table 2
Revised table of activities for block assembling after crashing activity "2"

Task #	Activity name	Optimistic time (t_{oi}) weeks	Most likely time (t_i) weeks	Pessimistic time (t_{pi}) weeks	Expected time=(T_{oi}+ $4T_i$+T_{pi})/6	St. Dev. s_i= (T_{pi}-T_{oi}) /6	Must be finished before this task starts	Variance (VAR)
1	Determining steel plate order	1.5	3	6	3.25	0.75	-	0.56
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5	Cutting parts for subassembly 2	0.5	1	2	1.08	0.25	2,3	0.06
6	Assembling subassembly 1	2.5	5	10	5.42	1.25	4	1.56
7	Assembling subassembly 2	2.5	5	10	5.42	1.25	5	1.56
8	Transporting subassembly 1 to block assembly site	0.5	1	2	1.08	0.25	6	0.06
9	Transporting subassembly 2 to block assembly site	0.5	1	2	1.08	0.25	7	0.06
10	Assembling Block 1-2	1.5	3	6	3.25	0.75	8.9	0.56

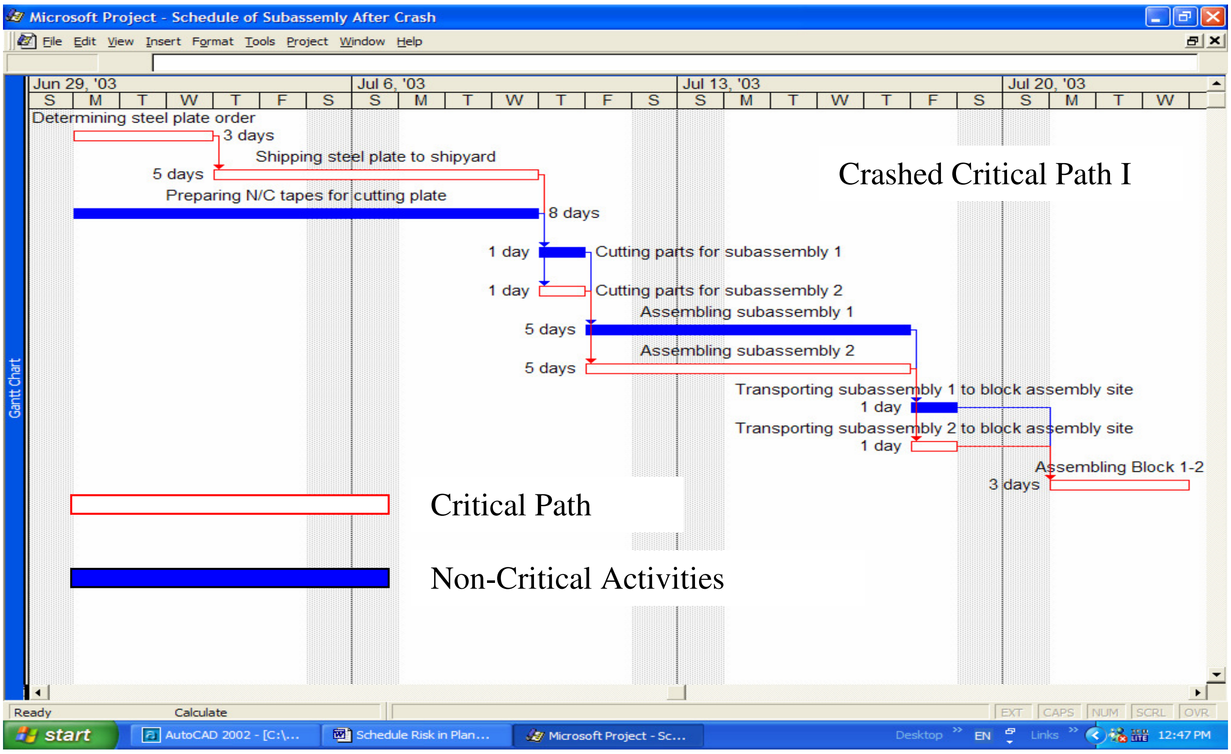

Fig. 3-a. Gantt chart for block assembling (critical path i) after crashing activity “2”.

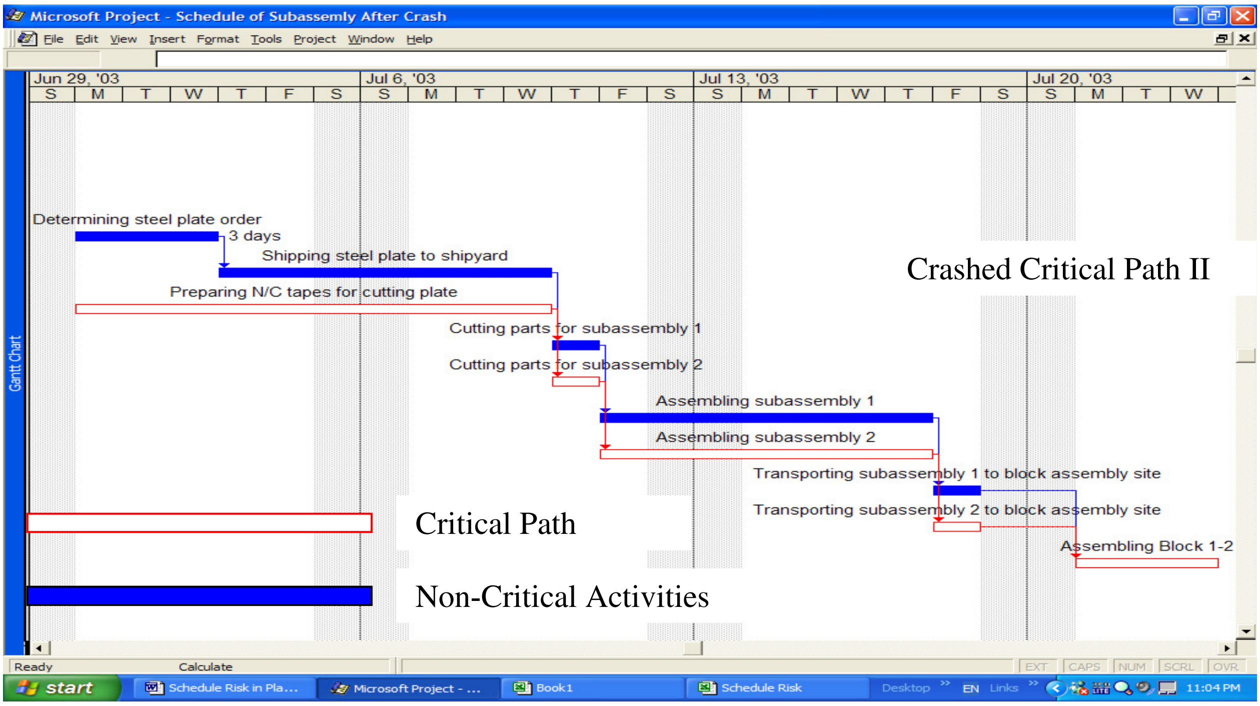

Fig. 3-b. Gantt chart for block assembling (critical path ii) after crashing activity “2”.

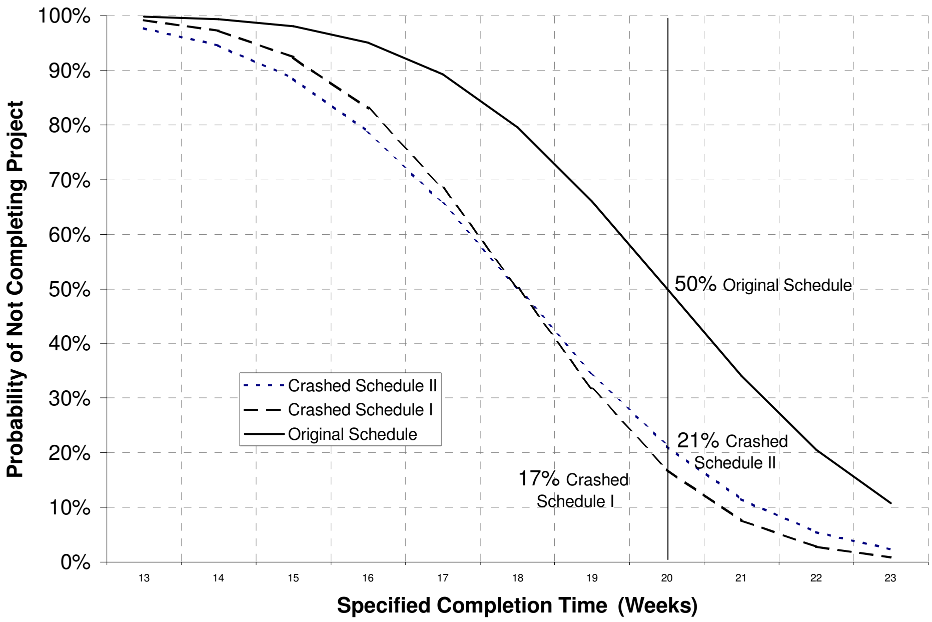

Fig. 4. Probability of not completing project as reduced by crashing activity "2".

using schedule risk assessment can bring to a project.

5. Conclusions and recommendations

1. Plainly it is possible to ask and answer what if questions relatively easily (e.g., what if a particular activity takes twice as long as expected - how will this affect the overall project completion time?).
2. Network analysis using Gantt chart is useful at the planning stage as it creates a structuring of thought about the project and clearly indicates the separate activities that we need to undertake, their relationship to one another and how long each activity will take.
3. Management can identify activities, at the start of the project, that were non critical but, as the project progresses, approach the status of being critical. This enables the project manager to "head off"' any crisis that might be caused by suddenly finding that a previously neglected activity has become critical.
4. Project crashing can be a powerful tool to decrease the risk of not completing the project
5. Further work is needed to integrate schedule risk and cost risk to evaluate the integrated risk of ship production projects.

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