



iJRASET

International Journal For Research in
Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 Issue: IX Month of publication: September 2017

DOI: <http://doi.org/10.22214/ijraset.2017.9161>

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Development of Schedule Reserve Using Monte Carlo Simulation

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Abstract: *This paper deals with the Schedule reserve using probabilistic project risk analysis .For this purpose three cases are used to step through the process. It deals with Risk based determination of reserve through Monte Carlo Simulation for critical path tasks. The focus of this paper is the use of the schedule risk assessment to establish the reserve and to recommend the extent of reserve to reduce the impact on schedule objectives. This provides the project manager with a means of evaluating the progress of the project activities, and a way to reasonably establish milestones for the project management.*

Keywords: *Schedule Reserve, Risk Analysis, Project Management*

I. INTRODUCTION

The necessity for budget reserve in project planning is widely recognized, but the need for a corresponding schedule reserve is generally not as universally acknowledged. The probabilistic project risk analyses have been performed for projects; the question has become how to more fully use the results of the schedule analyses to establish a schedule reserve.

Before the use of quantitative project risk analysis, milestones were based on the initial Time Count with Slack time as the only time reserved for delays. With this practice, the set of

Activities that have duration reserve is limited. In particular, critical path Activities, which do not have associated Slack, do not have reserve schedule time to use for delays. For other Activities, Slack was used on a “first-come, first-served” basis without allocation to other Activities. Thus, it was not possible to systematically allocate schedule reserve to project Activities.

A. Plan for Assessing Risks

Almost every large project is subject to schedule delays, and furthermore schedule delays often translate into cost overruns. A project risk assessment is performed to identify and mitigate potential contributors to cost increases and schedule delays. The assessment is used to establish reserve or reserve to contain potential overruns. The focus of this paper is the use of the schedule risk assessment to establish the reserve.

There are many different approaches to assessing the potential for schedule uncertainty. They may be as simple as doubling the amount of time necessary to complete the project or using another simple algorithm. Linear programming and decision tree analysis also may be used (Wendling 1999). Here Monte Carlo or random sampling simulations for project risk analysis of large projects (Kindinger 1999) has been used.

B. Monte-Carlo Simulation for Schedule

Monte Carlo simulations are used because they provide a way to assess each Activity individually and normal distributions do not have to be assumed.

Furthermore, the critical path is not static during the simulations, and more than one critical path is examined. The simulation allows opportunities to perform a sensitivity analysis, and it is easy to identify the confidence interval of the schedule.

Only MCS Can

- 1) Include uncertainty for each variable
- 2) Allow distribution adjustment and continuous value what-if scenarios to be compared
- 3) Allow realistic targets for cost and schedule to be set
- 4) Identify the identity and probability of alternate critical paths
- 5) Present a single “total project outcome” in economic terms with probability of occurrence

For time schedules, Monte-Carlo avoids the

problems of CPM and PERT Valuable output is a list of project activities with a probability for each that it lies on the critical path Alternatives can be evaluated rigorously and it is excellent for representing project contingencies

Monte-Carlo can handle correlation between

Activities.

II. PROJECT RISK ASSESSMENT METHODOLOGY

A general understanding of the project risk assessment methodology aids in the discussion of the application of the project risk analysis to determine reserve. The project risk assessment is performed in two basic steps: a qualitative analysis followed by a quantitative analysis. The identification of potential risks requires the systematic review of the entire project during which the technical, cost, and schedule risks are evaluated using project-specific risk rating criteria.

The qualitative assessments are then translated into numerical values that are used to develop the input data distributions, which in turn are fed into the quantitative model.

A. Potential Risk of Schedule Delay

Before reviewing an activity, the analyst defines the potential risks based on the features of the Activity. Schedule, cost, and technical risks cannot be considered independently, and cost and technical risks often influence the schedule risks

Risk factor rating criteria are used to guide the qualitative analysis of each Activity, which results in a risk rating of “high,” “medium,” or “low” for each Activity. The qualitative results and any specialized quantitative data are used to develop the uncertainty distributions for each Activity in the project risk model. Simulation models using tools such as Crystal Ball produce cumulative probability distribution functions (PDFs) that describe the confidence level given to the achievement of the project performance. The PDFs are used in developing the reserve recommendations for the project and each element of the Activity.

B. Reserve Analysis

Reserve is defined in *A Guide to Project Management Body of Knowledge* (1996) as “A separately planned quantity used to allow for future situations which may be planned for only in part (sometimes called the “known unknowns”). For example, rework is certain; the amount of rework is not. Reserve may involve cost, schedule, or both. Reserves are intended to reduce the impact of missing cost or schedule objectives. Reserves are normally included in the project’s cost and schedule baselines.” Because one of the purposes of the reserve analysis is to recommend the amount of reserve, the reserve is not generally included in the Time Count.

C. Estimation of Schedule Reserve

Two of the challenges associated with the allocation of schedule reserve (SR) are the existence of parallel paths and the ability to ensure that reserve is available for later Activities. The existence of parallel paths is addressed using the traditional methods of assigning Slack based on the durations of the parallel Activities. The second question of ensuring that reserve is available for later Activities is addressed by allocating the SR based on the risk of the Activity and the point-estimate duration of the Activity.

To develop the allocation of reserve, three cases are used to step through the process. Case I uses only the Time Counts to determine the SR; in other words, the Slack is the SR. Case II builds on Case I and uses the mean to develop the reserve.

Because the reserve is based on the mean values, the reserve can be calculated directly for each Activity as the difference between the point-estimate duration and mean value of the risk analysis distribution. The use of the mean is recommended by Wendling (1999) to develop reserve, and the analysis could be considered complete after this step. However, the reserve is also calculated at the 85th percentile confidence level to allow management at a higher level of confidence.

Case III develops the 85th confidence value from the Monte Carlo simulation. As Kindinger (1999) explains, the individual independent distributions cannot be simply added to obtain the corresponding point-value from the probabilistic sum of the distributions. Thus, the Activity-level contingencies must be prorated to be proportional to with their contribution to the project total duration. All of the cases are based on the same data in which the means and 85th percentile values are derived from a Monte Carlo simulation assessment. A simple project of six Activities with the relationships shown in figure is used in all three examples. For the sake of the examples, it is assumed that all Activities have finish-to start relationships with their predecessors. The critical path identified in the Time Count is Path A, which consists of Activities 1 through 4, each with point-estimate duration of 50 days.

Path B is composed of Activities 5 and 6, each with a Time Count duration of 25 days. In the examples, the sum of the duration of Activities 5 and 6 is less than the sum of the duration of Activities 2 and 3. This allows the Slack for Path B to be calculated using the differences between the two sums. The point-estimate durations do not include reserve.

1) *Case I: Time Count:* If a schedule risk assessment is not performed, the schedule reserve is based solely on the Time Count baseline. The only time available for the allocation of reserve is the Slack time. Thus, critical path elements do not have any available reserve.

$$SR = \text{Allocated Slack (AS)}$$

$$D = \text{Duration} = \text{Time Count (TC)} + AF$$

a) *Path A:* Because Path A is the critical path, the Slack for critical path Activities is 0; therefore, SR₁₋₄ = 0.

b) *Path B:* For large multi activity schedules the calculation of the Slack is complex, however, this paper will use a simplified Slack calculation.

The available Slack for Path B is the difference between the maximum allowable duration (durations of Activities 2 and 3) and the Time Count duration (durations of Activities 5 and 6.)

$$TC \text{ Path B} = TC \text{ Activity 5} + TC \text{ Activity 6} = 25 + 25 = 50$$

$$AS \text{ Path B} = (D \text{ Activity 2} + D \text{ Activity 3}) - TC \text{ Path B} = 100 - 50 = 50$$

Table 1: Case I: Path A

Activity	SR	Duration
Activity1	0	50
Activity 2	0	50
Activity 3	0	50
Activity 4	0	50

Table 2: Case I: Path B

Activity	SR	Duration
Activity 5	25/50*50=25	50
Activity 6	25/50*50=25	50

The available Slack along Path B could be allocated between Activities 5 and 6 in different ways. One approach would be to start the Activities as early as possible, this effectively grants the entire available Slack to Activity 6. Another common approach is to start the Activities as late as possible, effectively granting the entire available Slack to Activity 5. Finally, as illustrated below, the available Slack for Path B could be proportionally divided between Activities 5 and 6 based on their durations.

$$AS \text{ Activity} = (TC \text{ Activity} / TC \text{ Path}) * AS \text{ Path}$$

$$SR = AS \text{ Activity} = (TC \text{ Activity} / TC \text{ Path}) * AS \text{ Path}$$

Table 3: Results of Simulation

	Time Count TC	Mean (M)	Simulation Results(SR) 85%
Path A	200	265	280
Activity 1	50	60	62
Activity 2	50	70	75
Activity 3	50	75	88
Activity 4	50	60	63
Path B	50	67	75
Activity 5	25	37	45
Activity 6	25	30	32

2) *Case II: Mean*

In the second case, the mean from the Monte Carlo assessment is used to determine the reserve. The central limit theorem dictates that the mean of the entire path is the sum of the means of each Activity. The total schedule reserve for each Activity now has two components. First, there is the calculated uncertainty in the Activity duration, and second, any available Slack along the path to which the Activity belongs.

$$SR = (M - TC) + AS$$

$$D = SR + TC$$

- a) *Path A*: Because Path A is the critical path, the allocated Slack is 0, and the SR may be computed directly as the difference between the mean and the Time Count. Furthermore, the Activity-level duration is the mean duration of the Activity.
- b) *Path B*: The total Path B Slack is calculated using the same algorithm as Case I; the Slack is the difference between the duration of the sub path of Activities 2 and 3 and the duration of Path B. The durations are based on the mean value durations.

$$AS \text{ Path B} = (D \text{ Activity 2} + D \text{ Activity 3}) - (M \text{ Path B}) = (70 + 75) - 67 = 78$$

As in Case I, the total available Slack can be distributed using several approaches. Note from the following example that by using the mean values of the Activity durations in the proportional approach, a risk-based allocation of the available Slack between Activities 5 and 6 is obtained automatically. The SR is computed at the Activity level and the duration of the Activity is determined by adding the SR to the TC duration.

$$AS \text{ Activity} = (M \text{ activity} / M \text{ Path B}) * AS \text{ Path}$$

$$SR \text{ Activity}$$

$$= (M \text{ Activity} - TC \text{ Activity}) + AS \text{ Activity} = (M \text{ Activity} - TC \text{ Activity}) + (M \text{ Activity} / M \text{ Path B}) * AS \text{ path}$$

Table 4 Case II

Activity	SR	Duration
Path A		
Activity 1	60-50=10	50 + 10=60
Activity 2	70-50=20	50+20=70
Activity 3	75-50=25	50+25=75
Activity 4	60-50=10	50+10=60
Path B		
Activity 5	(37-25)+(37/67)*78=55	25+55=80
Activity 6	(30-25)+(37/67)*78=48	25+48=73

3) *Case III: 85th Percentile Confidence Level*

This case illustrates how a confidence level higher than the mean can be used in managing the project. Except at the mean, the deterministic

Sum and probabilistic sums are not equal. The sum of the Activity-level durations must be equal to the duration of the path. Therefore, each Activity must receive a prorated value of the entire path. The prorated value is proportional to the Activity's 85th percentile duration. The following formula is used to determine the prorated value.

$$TPC = \text{Activity prorated reserve} = PR85$$

$$PTC = \text{path total reserve} = SR85$$

Based on the Monte Carlo risk assessment above, for Path A, $\square 85\% = 62+75+88+63=288$

for Path B, $\square 85\% = 45+32=77$.

Table 5 : Case III

	Simulation Results(SR) 85%	Prorate Results 85%
Path A	288	283
Activity 1	62	(62/285)*280=61
Activity 2	75	(75/285)*280=74
Activity 3	88	(88/285)*280=86
Activity 4	63	(63/285)*280=62
Path B	75	75
Activity 5	45	44/77*75=43
Activity 6	32	32/77*75=31

Table 5 shows the calculation of the prorated 85% values. It should be noted that the sum of the simulation durations of the Activities is greater than the path duration, but the sum of the durations of the prorated Activities is equal to the duration of the path. The SR is based on the prorated 85th percentile value for each Activity.

$$SR = (PR85 - TC) + AS$$

$$D = TC + SR$$

a) *Path A*: As in Case I and Case II, because A is the critical path the available Slack is 0, thus, the duration is the prorated 85th percentile value.

b) *Path B*: As in Cases I and II, the total available Slack for Path B is calculated as the difference between the prorated 85th percentile duration of the sub-path formed by Activities 2 and 3 and the 85th percentile duration of Path B.

$$AS \text{ Path B} = (D \text{ Activity 2} + D \text{ Activity 3}) - (SR \text{ Path B}) = (74 + 86) - 75 = 85$$

Again using the proportional approach for dividing the available Slack between Activity 5 and Activity 6, their SRs are calculated using the same algorithms as Case I and Case II.

$$AS \text{ Activity} = (PR85 \text{ Activity} / SR \text{ Path B}) * AS \text{ Path}$$

$$SR \text{ Activity} = (PR85 \text{ Activity} - TC \text{ Activity}) + AS \text{ Activity} = (PR85 \text{ Activity} - TC \text{ Activity}) + (PR85 \text{ Activity} / SR \text{ Path B}) * AS \text{ Path}$$

Table 6: Case III

Activity	SR	Duration
Path A		
Activity 1	(61-50)+0=11	50+11=61
Activity 2	(74-50)+0=24	50+24=74
Activity 3	(86-50)+0=36	50+36=86
Activity 4	(62-50)+0=12	50+12=62
Path B		
Activity 5	(43-25)+(43/75)*85=67	25+67=92
Activity 6	(32-25)+(32/75)*85=43	25+43=68

4) Summary

Table 7

Case I	TC	AS	SR	TD
Path A	200	0	0	200
Activity 1	50	0	0	50
Activity 2	50	0	0	50
Activity 3	50	0	0	50
Activity 4	50	0	0	50
Path B	50	50	0	100
Activity 5	25	25	0	50
Activity 6	25	25	0	50

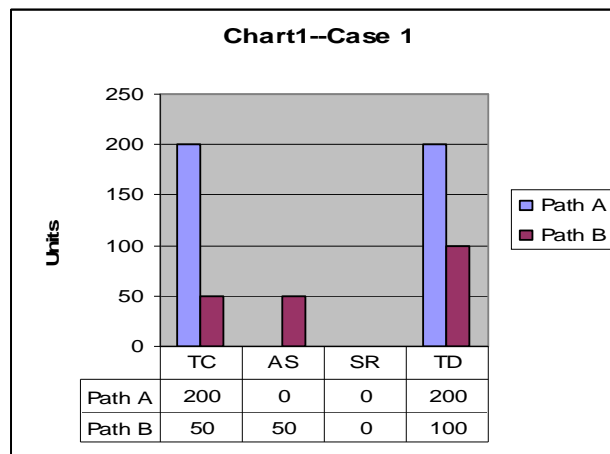


Table 8

Case II				
	TC	AS	SR	TD
Path A	200	0	65	265
Activity 1	50	0	10	60
Activity 2	50	0	20	70
Activity 3	50	0	25	75
Activity 4	50	0	10	60
Path B	50	78	17	103
Activity 5	25	43	12	55
Activity 6	25	35	5	48

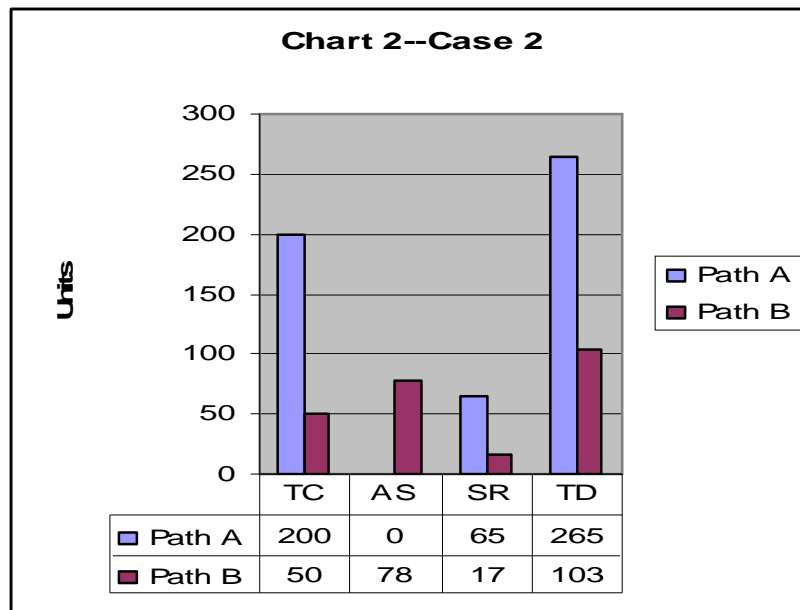
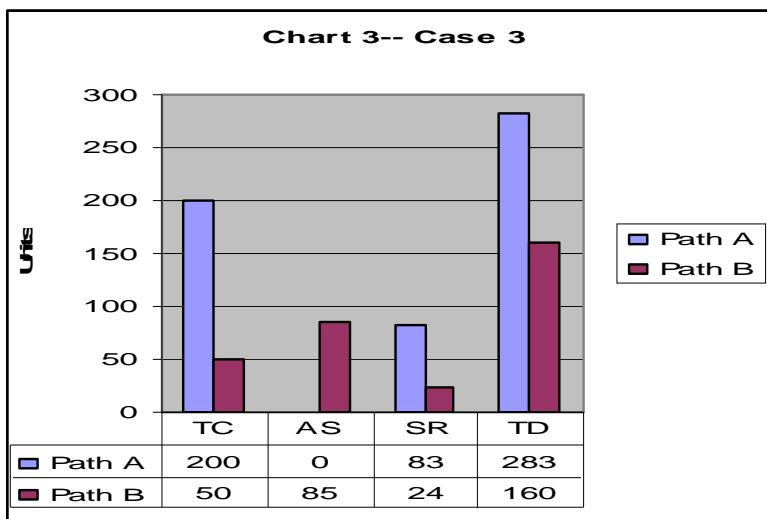


Table 9

Case III				
Path A	200	0	83	283
Activity 1	50	0	11	61
Activity 2	50	0	24	74
Activity 3	50	0	36	86
Activity 4	50	0	12	62
Path B	50	85	24	160
Activity 5	25	50	18	92
Activity 6	25	35	6	68



Tables summarize the results of the three example cases for the calculation and allocation of schedule reserve to the activities of the simple project network. On the table TC is the Time Count, AS is the available Slack, SR is the Schedule reserve, and TD is the total duration.

III. CONCLUSIONS

The teaming of Monte Carlo simulation assessments and a prorating algorithm for schedule reserve provides a means to determine and recommend a reserve level for not only the entire project, but also for the Activities of the project. The reserve calculations and allocations approach illustrated in this paper provide a risk-based determination of reserve for critical path Activities and a risk-based allocation of available Slack to non critical activities. This provides the project manager with a means of evaluating the progress of the project activities, and a way to reasonably establish milestones for the project management.

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