P1: a/b P2: c/d QC: e/f T1: g
c07 JWBT270-Mun March 16, 2010 14:15 Printer: Yet to Come

CASE STUDY: RISK-BASED SCHEDULE PLANNING WITH SIMULATION

Mark Rhoades is a lecturer at the Naval Postgraduate School at Monterey, California. He is a former U.S. Navy Commander and has served as the Deputy Program Manager at the NAVSTAR Global Positioning System Joint Program Office, a systems engineer at the Naval Air Systems Command, and the Program Manager of the Naval Aviation Depot Field Service Repair Teams. Mark has had years of experience in program management, program planning, reliability, and logistics. In addition to teaching graduate-level classes in risk management, he currently runs his own consulting business, Risk and Opportunity Management.

All organizations depend heavily on project planning tools to forecast when various projects will complete. Completing projects within specified times and budgets is critical to facilitate smooth business operations. In our high-technology environment, many things can impact schedule. Technical capabilities can often fall short of expectations. Requirements are insufficient in many cases and need further definition. Tests can bring surprising results—good or bad. A whole host of other reasons can lead to schedule slips. On rare occasions, we may run into good fortune and the schedule can be accelerated. Project schedules are inherently uncertain and change is normal. Therefore, we should expect changes and find the best way to deal with them. So why do projects always take longer than anticipated? The following discussion presents a description on shortcomings in the traditional methods of schedule estimation and how Risk Simulator can be applied to address these shortcomings.

Traditional Schedule Management

Traditional schedule management typically starts with a list of tasks. Next these tasks are put in order and linked from the predecessor to successor for each task. They are typically displayed in either a Gantt chart form or a network. For our discussion, we concentrate on the network. The duration for each task within the network is then developed. The estimated duration for each task is given a single point estimate, even though we know from experience that this estimate should be a range of values. The first error is using a single point estimate. In addition, many people who provide duration estimates try to put their best foot forward and give an optimistic or best-case estimate. If we assume that the probability of achieving this best-case estimate for one task is 20 percent, then the likelihood of achieving the

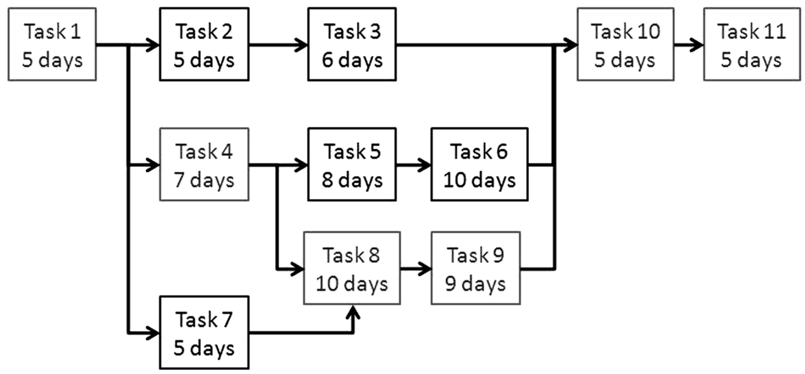


FIGURE 7.33 Schedule network.

best case for two tasks is merely 4 percent (20 percent of 20 percent), and three tasks yields only 0.8 percent. Within a real project with many more tasks, there is only an infinitesimal chance of making the best-case schedule.

Once the task duration estimates have been developed, the network is constructed and the various paths through the network are traced. The task durations are summed along each of these paths, and the one that takes the longest is identified as the critical path. Figure 7.33 illustrates an example network and critical path. The sum of task durations along the critical path is listed as the project completion date. In Figure 7.33, there are four paths through the network from beginning to end. The shortest/quickest path is tasks 1-2-3-10-11 with a total duration of 22 days. The next shortest path is tasks 1-7-8-9-10-11 at 34 days, and then path 1-4-5-6-10-11 at 36 days. Finally, the path 1-4-8-9-10-11 takes the longest at 37 days and is the critical path for this network.

So let us assume that this network of tasks is our part of a larger effort and some other effort upstream of ours has overrun by a day. Our boss has asked us to shorten our schedule by one or two days to get the overall effort back on track. Traditional schedule management has one target: shorten the longest duration item in the critical path. Another approach is to shorten every task on the entire critical path. Because the first technique is more focused, more prone to success, and creates fewer conflicts on our team, let us assume that we will use that one. Hence, we will want to reduce Task 8 from 10 days to 9 days to shorten our schedule and we will satisfy our boss or our customer. Let us leave the traditional methodology at this stage feeling satisfied with our efforts.

Probabilistic Schedule Management

If we agree that task durations can vary, then that uncertainty should be accounted for in our schedule models. A schedule model can be developed by creating a probability distribution for each task, representing the likelihood of completing the particular task at a specific duration. Monte Carlo simulation techniques can then be applied to forecast the entire range of possible project durations.

A simple triangular distribution is a reasonable probability distribution to use to describe the uncertainty for a task's duration. It is a natural fit because if we ask someone to give a range of duration values for a specific task, he or she usually supplies two of the elements: the minimum duration and the maximum duration. We need only ask or determine the most likely duration to complete the triangular distribution. The parameters are simple, intuitively easy to understand, and readily accepted by customers and bosses alike. Other more complex distributions could be used such as the Beta or Weibull but little, if anything, is gained because the determination of the estimated parameters for these distributions is prone to error and the method of determination is not easily explainable to the customer or boss.

To get the best estimates, we should use multiple sources to get the estimates of the minimum, most likely, and maximum values for the task durations. We can talk to the contractor, the project manager, and the people doing the hands-on work and then compile a list of duration estimates. Historical data can also be used, but with caution. While the current project may be similar to past projects, the previous projects usually contain several unique elements or combinations. We can use Figure 7.34 as a guide. Minimum values should reflect optimal utilization of resources. Maximum

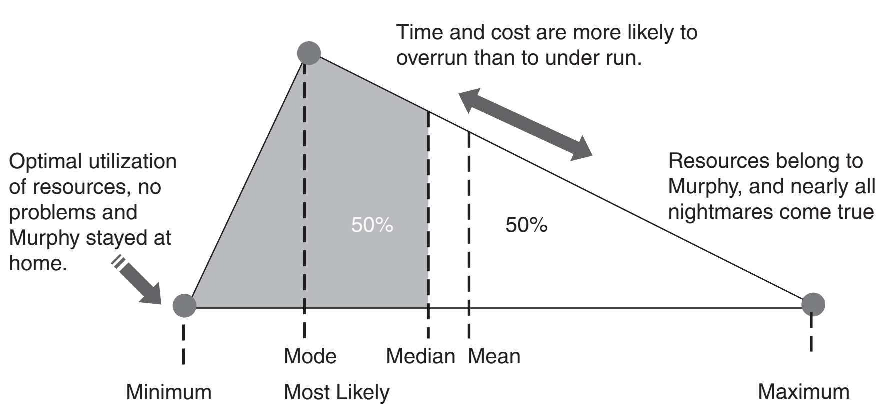


FIGURE 7.34 Triangular distribution.

TABLE 7.18 Range of Task Durations

Task #	Task Name	Dynamic Duration	Minimum	Most Likely	Maximum	Point Estimate
1	Stakeholder Analysis	5.78	4.5	5	6	5
2	Objectives Hierarchy	4.79	4.5	5	6	5
3	Decision Metrics Development	6.16	5.5	6	7	6
4	Functional Analysis	7.78	6	7	9	7
5	Primary Module Rqmts	9.22	7	8	10	8
6	Primary Module Development	10.12	9	10	13	10
7	Secondary Module Functional Analysis	5.42	4.5	5	6	5
8	Secondary Requirements Allocation	10.05	9	10	12	10
9	Secondary Module Development	9.40	8	9	10	9
10	Trade Studies	3.33	2.5	3	4	3
11	Final Development Specification	3.76	2.5	3	4	3

values should take into account substantial problems, but it is not necessary to account for the absolute worst case where everything goes wrong and the problems compound each other. Note that the most likely value will be the value experienced most often, but it is typically less than the median or mean in most cases.

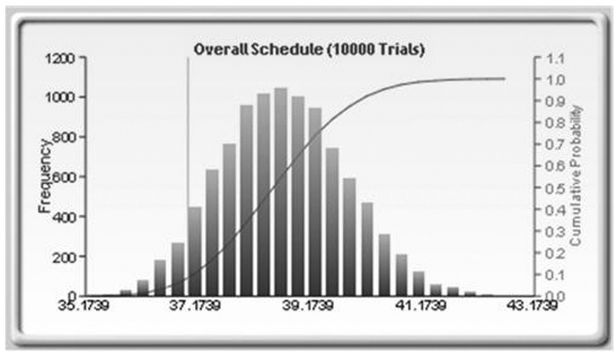
For our example problem, shown in Figure 7.33, the minimum, most likely, and maximum values given in Table 7.18 will be used. We can use Risk Simulator's input assumptions to create triangular distributions based on these minimum, most likely, and maximum parameters. The column of dynamic duration values shown in the table was created by taking one random sample from each of the associated triangular distributions.

After the triangular distributions are created, the next step is to use the schedule network to determine the paths. For the example problem shown Figure 7.33, there are four paths through the network from beginning to end. These paths are shown in Table 7.19 with their associated durations.

TABLE 7.19 Paths and Durations for Example Problem

Path1	Duration1	Path2	Duration2	Path3	Duration3	Path4	Duration4
1	5.78	1	5.78	1	5.78	1	5.78
2	4.79	4	7.78	4	7.78	7	5.42
3	6.16	5	9.22	8	10.05	8	10.05
10	3.33	6	10.12	9	9.40	9	9.40
11	3.76	10	3.33	10	3.33	10	3.33
		11	3.76	11	3.76	11	3.76
Total1	23.81	Total2	39.99	Total3	40.10	Total4	37.73

Overall Schedule Total >>>>>> 40.0968125 =MAX(Total1,Total2,Total3,Total4)



Type: Left-Tail ≤, Lower: -Infinity, Upper: 37.0000, Certainty: 8.2700%

FIGURE 7.35 Results of Monte Carlo analysis.

(Note: When setting up the spreadsheet for the various paths, it is absolutely essential to use the input assumptions for the task durations and then reference these task duration cells when calculating the duration for each path. This method ensures that duration of individual tasks is the same regardless of which path is used.) The overall schedule duration is the maximum of the four paths. In Risk Simulator, we would designate that cell as an Output Forecast. In probabilistic schedule analysis, we are not concerned with the critical path/near-critical path situations because the analysis automatically accounts for all path durations through the calculations.

We can now use Risk Simulator and run a Monte Carlo simulation to produce a forecast for schedule duration. Figure 7.35 shows the results for the example problem. Let us return to the numbers given by the traditional method. The original estimate stated the project would be complete in 37 days. If we use the left-tail function on the forecast chart, we can determine the likelihood of completing the task in 37 days based on the Monte Carlo simulation. In this case, there is a mere 8.27 percent chance of completion within the 37 days. This result illustrates the second shortcoming in the traditional method: Not only is the point estimate incorrect, but it puts us in a high-risk overrun situation before the work even has started! As shown in Figure 7.35, the median value is 38.5 days. Some industry standards recommend using the 80 percent certainty value for most cases, which equates to 39.5 days in the example problem.

Now let us revisit the boss's request to reduce the overall schedule by one day. Where do we put the effort to reduce the overall duration? If we are using probabilistic schedule management, we do not use the critical path; so where do we start? Using Risk Simulator's Tornado and Sensitivity Analysis tools, we can identify the most effective targets for reduction

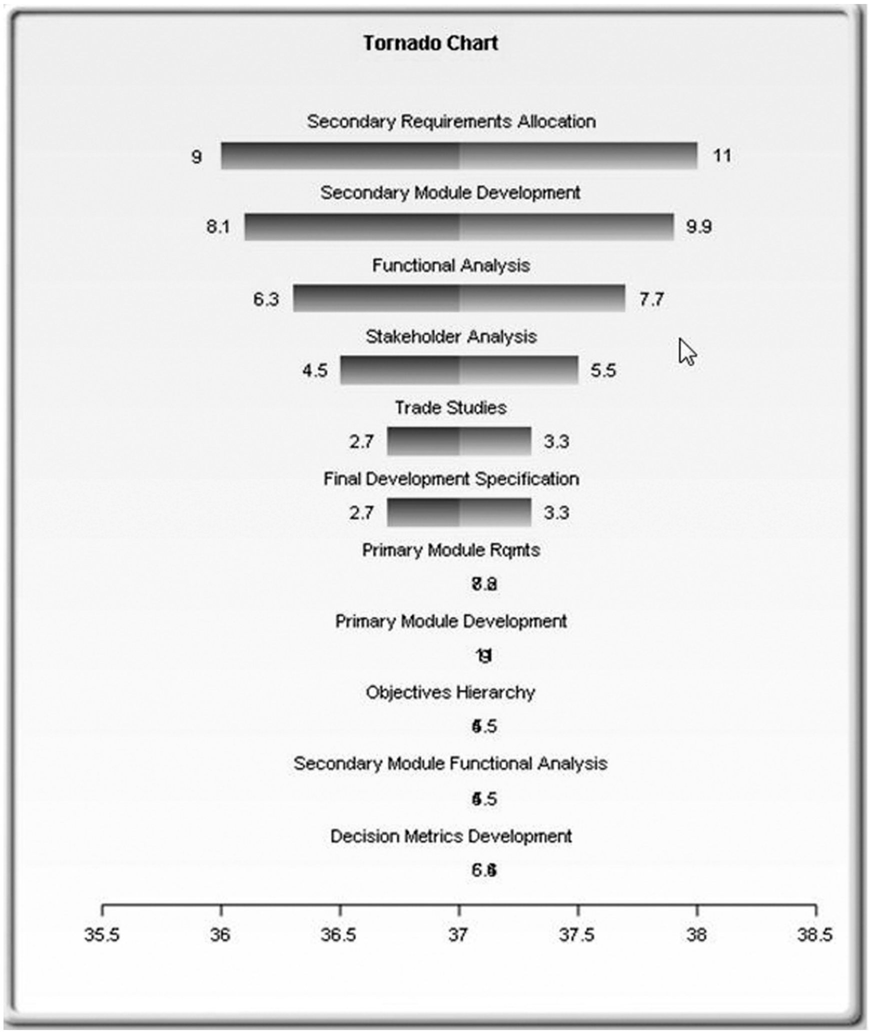


FIGURE 7.36 Tornado chart.

efforts. The tornado chart (Figure 7.36) identifies the most influential variables (tasks) to the overall schedule. This chart provides the best targets to reduce the mean/median values. We cannot address the mean/median without addressing the variation, however. The Sensitivity Analysis tool shows what variables (tasks) contribute the most to the variation in the overall schedule output (see Figure 7.37). In this case, we can see that the variation in Task 4

P1: a/b P2: c/d QC: e/f T1: g
c07 JWBT270-Mun March 16, 2010 14:15 Printer: Yet to Come

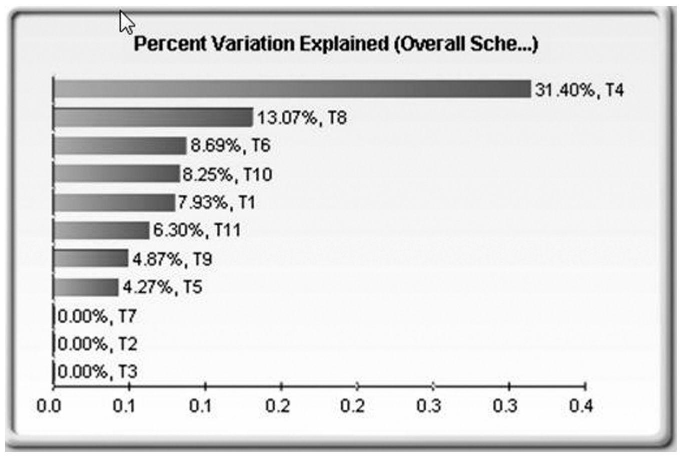


FIGURE 7.37 Sensitivity analysis chart.

is the major contributor to the variation in the overall schedule. Another interesting observation is the variation in Task 6, a task not on the critical path, is also contributing nearly 9 percent of the overall variation.

In this example, reducing the schedule duration for Task 4, Task 8, and Task 9 would pay the most dividends as far as reducing the overall schedule length. Determining the underlying reasons for the substantial variation in Tasks 4, 6, and 8 would likely give better insight into these processes. For example, the variation in Task 4 may be caused by the lack of available personnel. Management actions could be taken to dedicate personnel to the effort and reduce the variation substantially, which would reduce the overall variation and enhance the predictability of the schedule. Digging into the reasons for variation will lead to targets where management actions will be most effective, much more so than simply telling the troops to reduce their task completion time.

Using the network schedule model, we can also experiment to see how different reduction strategies may pay off. For example, taking one day out of Tasks 4, 8, and 9 under the traditional method would lead us to believe that a three-day reduction has taken place, but if we reduce the Most Likely value for Tasks 4, 8, and 9 by one day and run the Monte Carlo risk simulation, we find that the median value is still 37.84, or only a 0.7 day reduction. This small reduction proves that the variation must be addressed. If we reduce the variation by 50 percent, keeping the original minimum and the most likely values, but reducing the maximum value for each distribution, then we reduce the median from 38.5 to 37.84—about the same as reducing the Most Likely values. Taking both actions (reducing the Most Likely and

P1: a/b P2: c/d QC: e/f T1: g
c07 JWBT270-Mun March 16, 2010 14:15 Printer: Yet to Come

Maximum values) reduces the median to 36.83, giving us a 55 percent chance of completing within 37 days. This analysis proves that reducing the most likely value and the overall variation is the most effective action.

To get to 36 days, we need to continue to work down the list of tasks shown in the sensitivity and tornado charts addressing each task. If we give Task 1 the same treatment, reducing its most likely and maximum values, then completion within 36 days can be accomplished with a 51 percent certainty, and a 79.25 percent certainty of completing within 37 days. The maximum value for the overall schedule is reduced from more than 42 days to less than 40 days. Substantial management efforts would be needed, however, to reach 36 days at the 80 percent certainty level.

Rules for Schedule Risk Management

When managing the production schedule, use the best-case numbers. If we use the most likely values or, worse yet, the maximum values, production personnel will not strive to hit the best-case numbers thus implementing a self-fulfilling prophecy of delayed completion. When budgeting, we should create the budget for the median outcome but recognize that there is uncertainty in the real world as well as risk. When advertising the schedule to the customer, provide the values that equate to the 75 percent to 80 percent certainty level. In most cases, customers prefer predictability (on-time completion) over potential speedy completion that includes significant risk. Lastly, acknowledge that the “worst case” can conceivably occur and create contingency plans to protect your organization in case it does occur. If the “worst case”/maximum value is unacceptable, then make the appropriate changes in the process to reduce the maximum value of the outcome to an acceptable level.

How to Apply This Method to Larger Networks

Some could argue that this methodology is only good for small networks because it appears that you have to trace all of the paths from beginning to end. We can, however, break up the schedule network to make the problem easier for larger cases. In our example problem, all of the paths came together at Task 10. We can call Task 10 a Merge Event. We can break a large network up into smaller pieces utilizing the merge points to define the boundaries. To further illustrate this technique, we will use the schedule network shown in Figure 7.38.

In Figure 7.38, there are two merge points—Task 12 and Task 18. After we have created Input Assumptions for each task, we can set up our calculations. For this example, we should create the sum of the durations

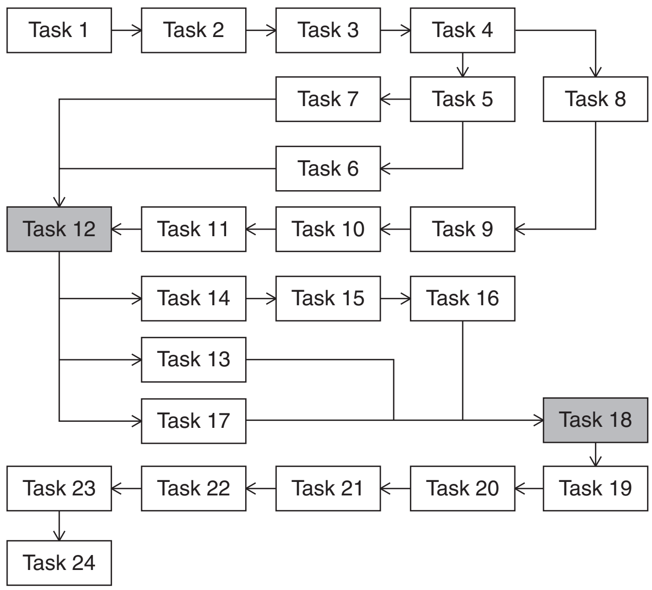


FIGURE 7.38 Example schedule network with multiple merge points.

for Tasks 1-2-3-4 as our first subtotal since these tasks are in series. The second subtotal would be equal to the maximum duration among Tasks 5-6, Task 5-7, and Tasks 8-9-10-11. We would then add the duration of Task 12 as the third subtotal. The fourth subtotal would be the maximum duration among Task 13, Tasks 14-15-16, and Task 17. Lastly we sum the durations of Tasks 18 through 24 as the fifth subtotal. We can then sum all of the five subtotals to determine the overall schedule duration. The spreadsheet cell that sums all five subtotals is set as the Output Forecast for our entire schedule network. The calculations are demonstrated in the spreadsheet shown in Figure 7.39.

Risk Simulator can also be used to take into account correlations between tasks. After we create the Input Assumptions, we can go back and use the *Tools | Edit Correlations* to account for correlations among tasks. For example, if previous experience or data indicates that as Task 8 takes longer the duration for Task 9 will also increase, then there is likely a correlation between those two tasks. If we have paired data, then we can use Risk Simulator's Distribution Fitting (Multi-Variable) tool to determine the correlation values between the two items. This tool also works with more than two items. If we have data from several previous cases, we can use this tool to determine the correlation matrix for all of the tasks. To build

	A	B	C	D	E
1	Task	MIN	ML	MAX	Input Assumption
2	1	2	5	10	5.33
3	2	5	10	15	10.48
4	3	30	45	90	47.12
5	4	5	10	15	13.11
6	5	30	45	90	74.60
7	6	5	10	15	14.04
8	7	15	25	60	33.53
9	8	10	20	60	16.05
10	9	5	15	30	16.31
11	10	5	10	15	9.88
12	11	15	25	45	39.91
13	12	15	20	30	18.98
14	13	20	30	45	37.55
15	14	30	45	60	50.76
16	15	15	30	45	29.34
17	16	5	10	20	8.11
18	17	10	15	25	11.13
19	18	15	30	60	33.60
20	19	10	15	30	11.40
21	20	15	30	60	40.63
22	21	5	10	15	12.09
23	22	30	60	90	44.41
24	23	5	10	15	11.70
25	24	5	8	12	11.70

G	H	I	J
Summations	Value	Formulas	Description
Subtotal1 =	76.03	=SUM(E3:E6)	Tasks 1-2-3-4
Subtotal2 =	108.13	=MAX(SUM(E7:E8),SUM(E7,E9),SUM(E10:E13))	Max of (Task 5-6,Tasks 5-7,Tasks 8-9-10-11)
Subtotal3 =	18.98	=E14	Task 12
Subtotal4 =	88.21	=MAX(E15,SUM(E16:E18),E19)	Max of (Task 13, Task 14-15-16, Task 17)
Subtotal5 =	165.52	=SUM(E20:E26)	Tasks 18-19-20-21-22-23-24
Total	456.87	=SUM(H3:H7)	Output Forecast

Forecasts

Name	Total	Number of Datapoints	5000
Enabled	Yes	Mean	460.5237
Cell	H9	Median	459.7741
		Standard Deviation	27.7741
Forecast Precision		Variance	771.3997
Precision Level	—	Coefficient of Variation	0.0603
Error Level	—	Maximum	557.3585
		Minimum	366.8121
		Range	190.5464
		Skewness	0.1385
		Kurtosis	-0.0754
		25% Percentile	441.0357
		75% Percentile	478.8738
		Error Precision at 95%	0.0017

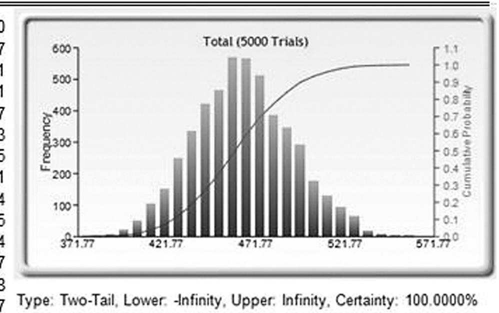


FIGURE 7.39 Example schedule spreadsheet with multiple merge points.

P1: a/b P2: c/d QC: e/f T1: g
c07 JWBT270-Mun March 16, 2010 14:15 Printer: Yet to Come

the most accurate forecast, we should account for correlations whenever we know they exist.

Conclusion

With traditional schedule management, there is only one answer for the scheduled completion date. Each task gets one duration estimate and that estimate is accurate only if everything goes according to plan, not a likely occurrence. With probabilistic schedule management, thousands of trials are run exploring the range of possible outcomes for schedule duration. Each task in the network receives a time estimate distribution, accurately reflecting each task's uncertainty. Correlations can be entered to more accurately model real-world behavior. Critical paths and near critical paths are automatically taken into account, and the output forecast distribution will accurately reflect the entire range of possible outcomes. Using tornado and sensitivity analyses, we can maximize the effectiveness of our management actions to control schedule variations and reduce the overall schedule at high certainty levels.