Interpreting Results of Quantitative Risk Analysis

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Get the habit of analysis - analysis will in time enable synthesis to become your habit of mind.
Frank Lloyd Wright, American Architect
1867 – 1959

The results of project risk analysis need to be properly interpreted to make meaningful decisions. In this article, we will discuss sensitivity analysis, interpreting frequency histograms, and calculating project contingency. In the end, we will learn how to rank events and event chains based on results of Monte Carlo simulation.

Interpretation Results of Analysis

Now that you have developed your project plan and added events and uncertainties and run a Monte Carlo simulation. In its raw form the results are just a series of statistical distribution. To get any real value, we have to understand what they mean. One of inherent problems with probabilistic calculations is that go against our common sense, in real life if we perform a task, there is only one result, but Monte Carlo provides us with a whole range of results (distributions) . For example, you are going out for dinner with your friends and tell your baby sitter it will take somewhere between 2 and 3 hours. In reality, it could be 2 hours 15 minutes, or it may be 2 hours and 45 minutes, but it cannot be both at the same time. The question is what time should be used? Let's take a look what can we get from Monte Carlo simulations.

Many risk analysis software tools offer results in very simple table format (Table 1):

Results	Project Duration	Project Finish Time	Project Cost
Deterministic	20 days	Feb 20, 2016	$45,000
Low (e.g. P10)	22 days	Feb 22, 2016	$52,000
Base (Mean)	26 days	Feb 26, 2016	$57,500
High (e.g. P90)	31 days	March 3, 2016	$61,400

Table 1. Results of analysis in a simple table format

These results are easy to interpret. It would mean that because of risks on average (mean) the project would increase by 6 days and 12,500.

The results of analysis can be also presented in the form of frequency histograms and cumulative probability plots. Please take a look on Figure 1. It represents three very common cases of which you should be aware. In this particular example, we have used a statistical distribution for cost, but similar cases may occur for duration, work, and other parameters.
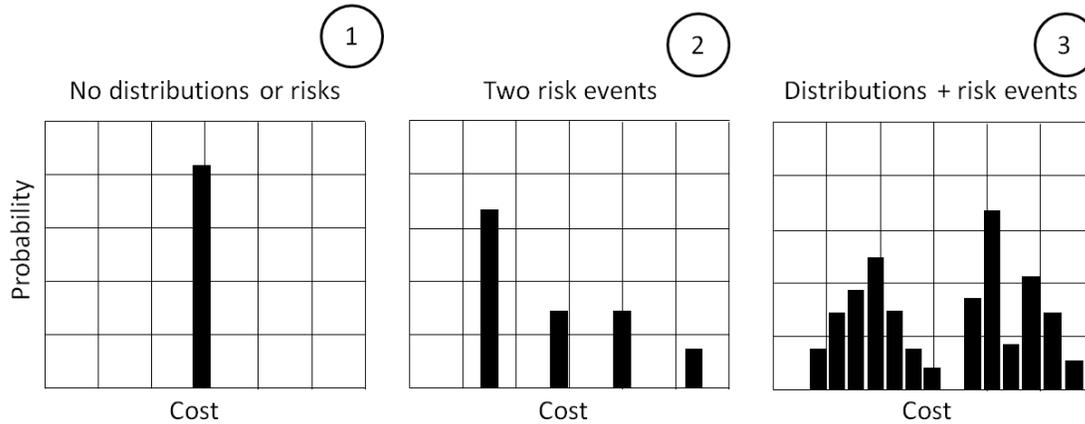

Figure 1. Three common cases of statistical distributions.

1. All costs are the same; there are no uncertainties or risk events affecting task or project cost.
2. This task or project has two risk events impacting cost. If there are only two events, why do we have four bars? One of the bars is the original cost (no risks). The second and third bars are costs when the two risks occurred separately. The last bar is represents cost when two risks occurred simultaneously.
3. Bimodal distribution where we see the interaction of uncertainty and risk events. In the case, the left group most likely represents cost uncertainty that is defined using a statistical distribution. These distributions model the inherent variability that occur due to small fluctuations that might occur to cost. The right group most likely represents result of risk events impacting cost. These risk events provide significantly greater impact than "noise", defined by statistical distributions.

Most project risk analysis software applications provide tools for analyzing frequency histograms and cumulative probability plots. We can use sliders or guides to determine the probability that cost or duration will be greater or below certain values. We can also place lines associated with low, base and high estimates of duration and cost which can be expressed as percentiles.

Managing Project Contingencies

Project contingency (also referred to as margin or management reserve) is additional time or budget that can be added to the project plan account for the possible variance from uncertainty and events and ensure that the project has a high probability of success.

Before we discuss how we should set contingency, lets take a look at two common practices that we don't recommend you use:

1. Project planners are often motivated to create shorter and less costly schedule to win a bid or get a project approved. For example, you are much more likely to have a project approved if you provide an estimate of $700 M as opposed to $1 Billion without reducing scope. So how can they reduce estimated costs without reducing scope? It's very simple actually, just assume that there will be no unexpected problems and reduce contingency accordingly. This approach to project planning is a very common phenomenon for large infrastructural projects as the scope is so large, it can be easier to obfuscate the true cost of risk. We don't recommend this approach as it tends to lead to large cost and schedule over runs.
2. Project planners in small projects may just choose to add additional contingency to account for all possible issues and therefore they will not blamed if project is delayed and overtime. The problem with this approach is that if you use unrealistically high contingencies, either as schedule margin or management reserve, this requires the organization to hold back resources and results in inefficient use of scarce resources and the inability to take advantage of opportunities.

So if cannot use these methods, how can we determine a realistic contingency for a specific project? The answer as you can probably guess, can be determined using the results of the Monte Carlo analysis. Remember, the analysis takes into account risks and uncertainties and provides statistical distributions that tell us what the chance is that we will get a certain result. So we can extend this to generate risk adjusted contingency. For example, we could determine our contingency based on p80 for cost and schedule. To do this, we would run the Monte Carlo risk analysis and calculate the contingency based on the difference between the original project plan and the P80 results. Once we have calculated this contingency, we would put them into the plan as buffers. During project execution, we would manage the project using the original plan and monitor the buffers. As risk and uncertainties occurs, it will consume the buffer, but as long as the buffer exists, the project would be completed on time and schedule. This approach is part of Critical Chain Method.

Sensitivity Analysis, Tornado and Scatter Plots

One thing that project managers always want to know, is what task should they be most worried about, which one could have the most impact on their project? If a task is not on the critical path it may not have any affect on project duration, unless it is impacted by risks. Tasks, which have the most potential to affect the project parameters such as duration or cost, are called *crucial tasks*. This term is used to distinguish it from critical tasks, which are on the critical path of the project schedule.

We can identify crucial task using *sensitivity analysis*. In general, sensitivity analysis determines how uncertainties in the output of a mathematical model is impacted by

different inputs. In our case, sensitivity analysis determines how uncertainties in project duration, cost and other parameters are affected by uncertainties in task parameters.? Let's assume that each task is a spring and each spring has different stiffness. Tasks with less stiffness will have more uncertainty, that is the will expand or contract more if impacted by other tasks. We are trying to move each spring to try to measure response of the last task (Figure 2). Tasks, which have the most affect on the movement at the end of our series of springs (the schedule) are the most crucial tasks. Any risks that are assigned to these tasks need to given high priority to understand how they can be managed.
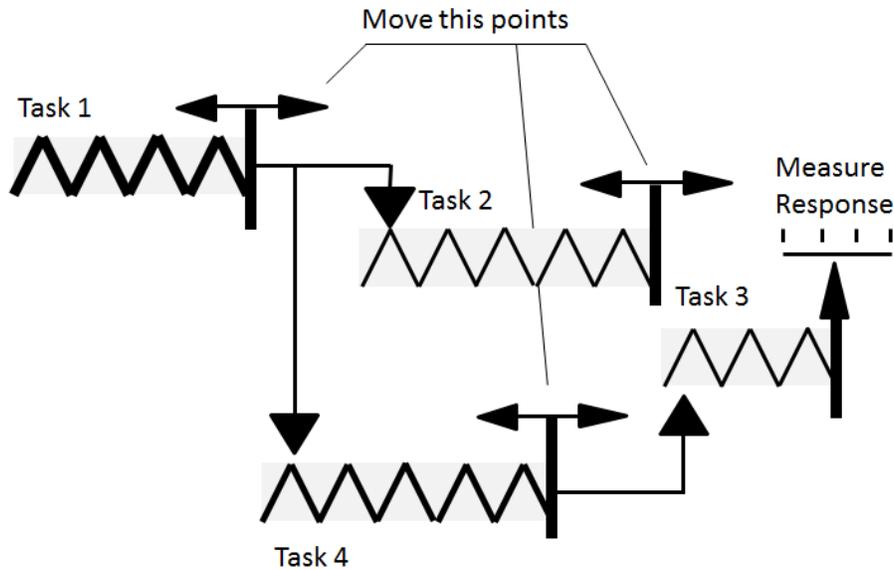

Figure 2. "Spring Analogy" for Sensitivity Analysis

We can identify crucial tasks by calculating the correlation between project parameters and task parameters. This is done using correlation coefficients, such as the Spearman correlation coefficient. Spearman is a nonparametric measure of the statistical dependence between two variables. When you perform Monte Carlo simulations, you will get a set of results for duration, cost, and other parameters for each task as well as for project.

Let assume that you want to calculate correlation coefficient for task duration and project duration. Spearman formula compares the result for task and projects on each iteration of Monte Carlo simulation. If a longer task duration always corresponds with larger project duration and smaller duration always corresponds with smaller project duration, correlation coefficient will be 1. If there is no relationship between two variables, the correlation coefficient will be zero. Please note that correlation coefficient does not depend on the nature or units of a variable, so you can calculate correlation coefficient between virtually anything, for example, between lag between tasks and project cost. There are the most common types of sensitivity analysis of a project:

- Project duration vs. task duration
- Project finish time vs. task finish time

- Project cost vs. task cost
- Project success rate vs. task success rate
- Project cost vs. task duration (in case if variable cost associated with resources)

Results of sensitivity analysis can be presented as Tornado Chart (Figure 3). It is called a Tornado chart due to the characteristic shape the bars form that resemble the cone of a tornado.
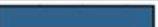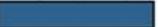
	Task Name	Task...	Coefficient	Tornado Chart
1	Task: What is the demand characteristic of your pr	22	0.72	
2	Task: Divide Business Plan Work by Experience	5	0.72	
3	Task: How can you reach your customers ?	11	0.72	
4	Task: Develop a description of your "Typical" Custc	9	0.72	
5	Task: What is the demand level for the product	21	0.65	
6	Task: Launch Business Plan	2	0.64	
7	Task: Meet to discuss new business strategy	4	0.61	
8	Task: Who are the customers for your Business	7	0.60	
9	Task: What is the potential market share ?	10	0.56	
10	Task: Who are your Competitors ?	15	0.53	
11	Task: Who will be your competitors	13	0.51	
12	Task: Will you be competing directly with competito	17	0.46	
13	Task: How effective are your competitors ?	16	0.42	

Figure 3. Example of Tornado Chart: Project Duration vs. Task Duration.

All tasks are sorted based on the correlation coefficient. Tasks with higher correlation between their duration and project duration are crucial and listed at the top.

Scatter plots can be also a valuable tool for sensitivity analysis (Figure 4). Each point on this chart represents result of one iteration of the Monte Carlo simulation. If points are widely dispersed, it indicates that project duration is not strongly correlated with task duration. If points appear to be aligned in one direction, it would mean that project and task duration are strongly correlated.
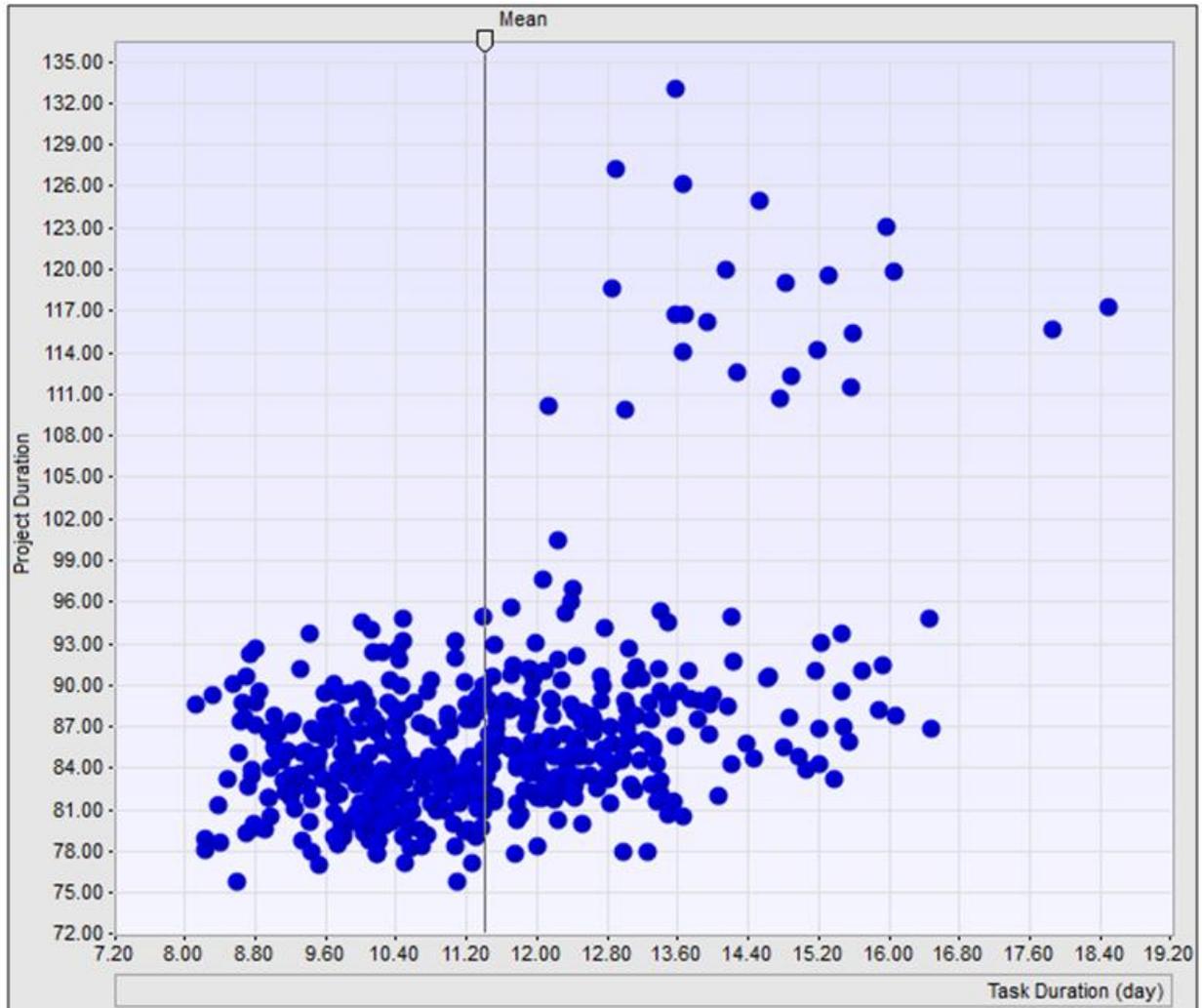
Figure 4. Scatter plot: Project Duration vs. Task Duration.

Sometimes different parameters may have "spurious correlation". Spurious comes from the Latin word spurious, which means illegitimate or false. A popular example of this is how people used to think that the stock market was correlated with the length of skirts. As skirts went up, so did stock markets according to this theory. However, most likely this is due to some other confounding factor and therefore, whenever we do see correlations that are unexpected, further investigations are required.

Critical Indexes

Here is an example of project schedule (Figure 5). Task 1 and Task 2 have uncertainties defined by a statistical distribution. Let's perform a Monte Carlo simulation of this schedule.
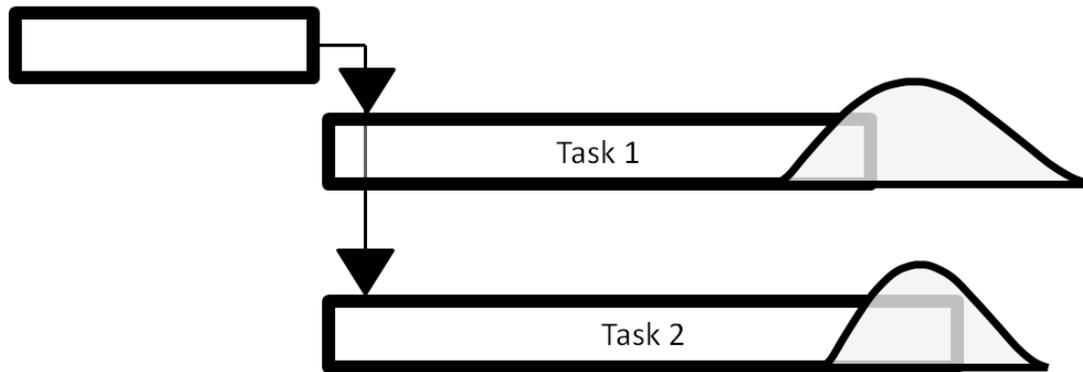
Figure 5. Calculation of critical indexes.

What we will discover is that different iterations of the Monte Carlo simulation Task 1 will be on the critical path, but on other iterations, Task 2 will be critical. *Critical Index* is an indicator which shows how many times the task is on the critical path during a Monte Carlo simulation. Critical indexes are a useful measure, as it can be used to prioritize the tasks and associated risks that must be management and monitored closely.

Risk Prioritization in Quantitative Analysis

Now we will return to Event Chain Methodology, in particular to Principle 5, which deals with the analysis of the schedule with event chains. We can extend this process to use Monte Carlo simulations to prioritize events and event chains. Remember, as part of our explanation of qualitative risk analysis, we learned how to prioritize risks based on the risk score. Now, through the use of Monte Carlo simulations, we can perform a more accurate analysis. Here is an example.

Two pirates, Jonny Death and Orlando Plume found that a treasure chest was buried beneath the parking lot of the Miami Dolphin's Stadium and are planning to dig it out in the morning. However, Captain Barabusa, their arch rival has been keep a close eye on the duo and suspects that they have discovered something and intends to arrive at the parking lot at exactly the same time. But our two clever pirates have a plan; while Jonny excavates the treasure chest, Orlando will attempt to fool Barabusa by telling him that Jonny has just been hired to repair the sewer and send Barabusa off in the wrong direction. As part of their plan, they created a project schedule (Figure 6).

Task Name	Base Dur	8AM-10AM	10AM-12PM
Dig a chest	3 hr		
Pull a chest	1 hr		
Disorient	2 hr		
Run	0 hr		

Figure 6. Project Schedule and Risks Assigned to Tasks

The final question is how Jonny and Orlando are going to share the treasure. After some discussion, they decide that whoever assumes the most risk should receive the largest share of the treasure. They also agree that the most important risk is that which has the potential to cause the greatest delay in the project. They identified 3 risks (Table 2):

	Risk	Probability	Delay of the task this risk is assigned to
1	Parking lot concrete is stronger than expected	20%	20%
2	The chest is heavier than expected	20%	20%
3	Captain Barabusa may be smarter than expected and it will take longer to confuse him	90%	80%

Table 2. List of risks

In quantitative analysis, the impact of risks is calculated based on the correlation between specific changes in duration, cost, or other parameter caused by the risk occurring and changes in the overall project duration, cost, or other parameters.

Based on this risk breakdown structure, Jonny will have to deal with the first two risks, while Orlando with deal with the last one. Orlando argues that he is assuming the most critical (90% chance that this risk will cause 80% delay) and that he deserves greater share of treasure. If we were performing qualitative analysis, where the risks are not assigned to the project schedule, he would be absolutely correct. However, in quantitative analysis that uses Monte Carlo simulations, the results can be decidedly different.

Here is how the risk analysis works in our particular example. In each Monte Carlo simulation, changes in duration caused by particular risk are calculated. For example, in simulation 1 due to the risk "Parking lot concrete is stronger than expected" Task 1 experiences a delay of 0.6 hours. The table below shows an example of Monte Carlo results (in hours) (Table 3):

Simulation	Task duration increase due to Risk 1: Parking lot concrete is stronger than expected	Task duration increase due to Risk 2: The chest is heavier than expected	Task duration increase due to Risk 3: Captain Barabusa is smarter than expected and it will take longer to disorient him	Project Duration
1	0.6 (20% increase of 3 hour duration)	0	1.6 (80% increase of 2	4.6

			hour duration)	
2	0	0.2 (20 % increase of 1 hour duration)	1.6	4.2
3	0	0	1.6	4
4	0.6	0	1.6	4.6
5	0	0	1.6	4
6	0	0	0	4
7	0	0	0	4
8	0	0	1.6	4
9	0	0	1.6	4
10	0	0.2	1.6	4.2
…	…	…	…	…
Correlation Coefficient	0.80	0.55	0	

Table 3. Duration changes on each iteration of Monte Carlo simulation

So the correlation coefficient is calculated between increases in duration caused by specific risks (columns 1, 2, and 3) and project duration (column 4). Spearman Rank Order correlation coefficient between risk 3 and project duration equals zero. Why? Because the task "Disorient Barabusa" is not on the critical path. Even if the duration of the task increases by or 1.6 hours ((80%) due to the risk and reaches 3.6 hours, it will still be less than the duration of Jonny's tasks: 3 hours +1 hours = 4 hours. It means that risk 3 does not affect project duration at all and the impact of this risk equals 0. However, the correlation coefficient is not yet the "risk impact". Here is the problem. Let us assume that our project has only one task "dig treasure" and one risk "Parking lot concrete is stronger than expected". What would be the correlation coefficient between changes in duration caused by the risk and project duration? The answer is 100%. It means that each time the risk occurs, the duration will increase. Now, what happens if this risk increases duration 90%, rather than 20%. The correlation coefficient will be the same. Spearman Rank Order correlation coefficient is the same when all values are multiplied by one number.

To avoid this problem the following calculation algorithm is used:
1. Calculate *correlation coefficient* as a result of Monte Carlo simulation as described above.
2. Calculate the project duration or cost with and without risks. Project duration with risk is the mean project duration. In our case project duration without risks and mean project duration as a result on Monte Carlo simulations (with risks) equals 4 hours.
3. Calculate the *impact coefficient = project duration with risk / (2 * project duration no risks)*. In our case impact coefficient equals 0.5.
4. Calculated *risk impact* equals *correlation coefficient* multiplied on *impact coefficient*. In our case impacts will be 40% = 0.8 * 0.5 * 100% and 27.5% = 0.55 * 0.5 * 100% for risks 1 and 2. Impact of risk 3 will be zero.

Project risk register with calculated risk impact and score is shown on Table 4.

	Risk	Probability	Calculated Impact	Score
1	Parking lot concrete is stronger than expected	20%	40%	8%
2	The chest is heavier than expected	20%	27.5%	5.5%
3	Captain Barabusa is smarter than expected and it will take longer to confuse him	90%	0%	0%

Table 4. Risk register with calculated risk impact.

From this we can calculate that a risk that leads to a doubling of project duration or has an impact 100%. Why two times and not three or five? It is actually an arbitrary value: however; once we adopt this value and use it at an organizational level, it allows us to consistently compare the impact of risks across multiple projects.

Finally, we calculate the risk scores as the risk probability multiplied by the risk impact and rank all risks based on the these scores. So in our story, Jonny should receive the greater share of the treasure because based on the project duration criteria our pirates choose, his risks have the most potential to increase the project duration.

Calculated Risk Probability

In the previous example, we assumed that one risk is assigned one task: a simple 1 to 1 relationship. But what happens if the risk is assigned to multiple tasks? Here is an example. Mexican drug lord El Stuppo wants to escape from jail (Figure 7). To do so, he is digging a tunnel from his side, and his associate is digging a tunnel from the opposite side. They are hoping to meet somewhere in the middle. But there is a risk that the tunnel may collapse. So there is a single risk, but we have to assign it to different tasks: "El Stuppo digging" and "Associate digging" with probabilities of 30% and 40% respectively. What would be the total probability of this risk?
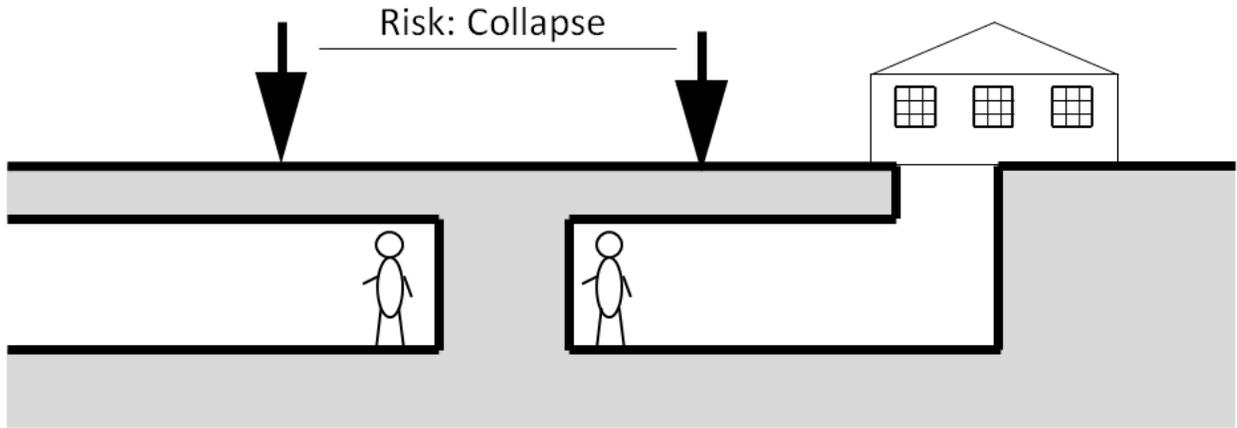
Figure 7. Calculating the probability of one risk assigned to multiple tasks

Everything depends how these assignments are correlated. Let's assume that the collapse is caused by heavy rain, which can occur at the same time at both sides of the tunnel. In this case, the risk assignments are correlated and probabilities are equal to maximum probability of both assignments: 40%. If risk assignments are not correlated , then probability is calculated how it is shown in Table 5.

Simulation	Assigned to Task "El Stuppo digging"	Assigned to Task "Associate digging"	Total for the risk
1	Occurred		Occurred
2		Occurred	Occurred
3	Occurred	Occurred	Occurred
4			
5			
6		Occurred	Occurred
7			
8			
9		Occurred	Occurred
10	Occurred		Occurred
Probability	30%	40%	60%

Table 5. Calculation of probability of risk occurrence for two risk assignments

Calculated Impact and Probabilities of Event Chain

In additional to calculating probability and impact of individual risk events, we can rank event chain. To do this, we need to investigate if the event chain is has been fully executed. In some cases one event can occur, but it will not trigger another event. Remember that receiver event may be triggered with certain probability. Then we will calculate the cumulative impact of the event chain, rather than the individual risks. If an event chain is fully executed, the cumulative impact of this event chain on all tasks to which the events from the chain are assigned is calculated. The next step is to

calculate the correlation between event chain impacts and project results. Again this is a similar process to the analysis we perform on individual risk events and this will allow us to rank event chain based on how they impact specific project parameters.