



## PROJECT RISK MANAGEMENT USING MONTE CARLO SIMULATION AND EXCEL

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**Abstract:** *In every project, especially in software and IT projects, there is the need to perform an elaborated risk management. One main task that often causes problems is the quantitative risk analysis. In this article we will show how to deal with this by using a well-known standard product: EXCEL.*

**Keywords:** *risk management, Monte Carlo simulation, PERT, Excel*

### 1. INTRODUCTION

In every project, especially in software and IT projects, there is the need to perform an elaborated risk management ([1] chapter 11, [2] chapter C3, as a first reading I recommend [3]). This risk management process includes several steps:

#### *Step 1: Risk management planning*

The risk management plan describes how risk management will be structured and performed on the project. The risk management plan includes the methodology, the roles and responsibilities, the risk budget, the timing, the risk categories etc.

#### *Step 2: Risk identification*

Risk identification determines which risks might affect the project and documents their characteristics. In this phase a lot of creativity techniques (e.g. brainstorming, Delphi technique) may be applied. The result should be a risk register that contains the identified risk together with their causes, possible responses etc.

#### *Step 3: Qualitative risk analysis*

Qualitative risk analysis includes methods for prioritizing and evaluating the identified risks for further analysis. Here you can also find the application of a variety of creativity techniques (e.g. brainstorming, expert interviewing, and Delphi

technique). The result should be an update of the risk register that now also contains an estimation of the probability (density) of the occurrence and the impact of a risk. Perhaps you will detect dependencies between several risks at that stage.

#### *Step 4: Quantitative risk analysis*

During the quantitative risk analysis the individual risks are modeled together. Here modeling techniques as Monte Carlo simulation or decision trees are used. The quantitative risk analysis should provide an impression of the probabilistic analysis of the whole project and not of the different individual risks.

#### *Step 5: Risk response planning*

Risk response planning is the process of developing options, and determining actions to enhance opportunities and reduce threats to the project's objectives. Beside the acceptance of risk, you can also try to avoid, reduce or transfer the risk or to mitigate the impact.

#### *Step 6: Risk monitoring and control*

During the whole project the identifying, analyzing, and planning for newly arising risks is a permanent process. You also have to keep track of the identified risks and those on the watch list, reanalyzing existing risks, monitoring trigger conditions for contingency plans, monitoring residual risks, and reviewing the execution of risk responses.

Especially in the fourth step a lot of stochastic

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analytic methods are needed, which makes this step a little complicated. We want to demonstrate this with two examples. Afterwards we will solve these examples by using Monte Carlo methods with Excel.

Empirical studies (e.g. [4]) show that risk management practices in project management is not widely used. One reason for this might be the fact that risk models normally have a high complexity and also need some mathematical and statistical background. Another reason is that the existing software packages are to some extent black boxes that offer only little opportunity to model very individual situations with e.g. given conditional probabilities. But these aspects can easily be overcome by using Monte Carlo simulation by means of Excel. Although there are already some textbooks and articles that introduced these techniques into risk management (e.g. [5], [6]), most of the basic textbooks or article do not even mention Monte Carlo simulation (e.g. [2], [7]) or just present the very elementary basics (e.g. [9], [10]). Therefore one main objective of this paper is to show that you can model very complex situations with models that can easily be created and solved with the well known tool Excel.

## 2. MONTE CARLO SIMULATION IN EXCEL

As everybody knows Monte Carlo simulation is a method that relies on repeated random sampling from given distributions [8]. Because of their reliance on repeated computations and random or pseudo-random numbers, Monte Carlo methods are most suited to calculation by computers.

By this the starting point of any Monte Carlo simulation is always the generation of random numbers that follow a given distribution. Theoretically you can get random numbers that follow any distribution as long as you know the inverse of the distribution function, because then you can create random numbers that are uniformly distributed in the interval [0, 1] and take the inverse of the distribution function. (See Fig. 1 & 2)

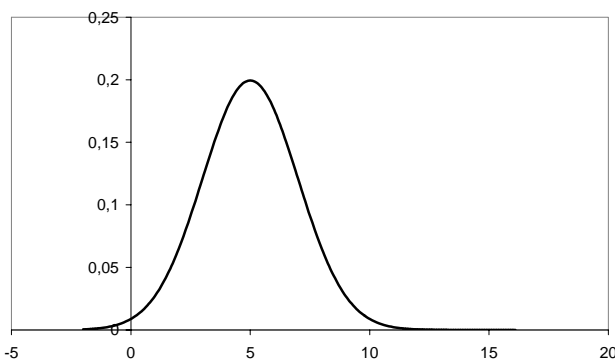


Fig. 1 – The density of a normal distribution

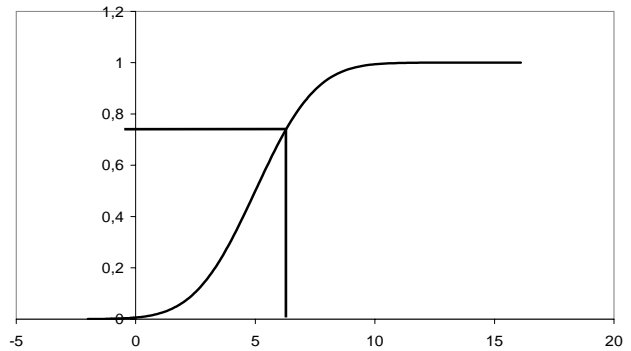


Fig. 2 – The distribution function and the indicated inverse of a normal distribution

In Excel there are some inverse functions of distributions already implemented like

- Beta distribution
- Chi-square distribution
- F-distribution
- Gamma distribution
- Lognormal distribution
- Normal distribution
- t-distribution.

If there is the need of further distributions there is on the one hand the possibility to create them as user defined functions by using a VBA-macro. On the other hand there are a lot of free add-ins available in the net.

For example in the internet you can find the products eSIM [11] and @RISK [12] with additional distributions. We normally install eSIM because it offers a triangular distribution, which is quite intuitive in practical work, because you have to estimate the optimistic and the pessimistic values and the most probable value in between. Besides this, eSIM offers some more distributions like the exponential and the Poisson distribution.

## 3. TWO CASES

### CASE 1

In the first example we want to consider the net of a project and we want to analyze the duration of the whole project. For this we estimated the distributions of the duration of the several tasks. You can find the information in fig. 3 and table 1.

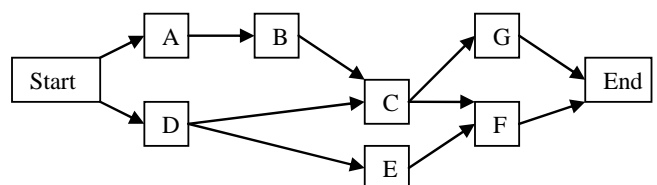


Fig. 3 – Network plan of the project

**Table 1. Duration of the activities**

Activity	Predecessor	Distribution of Duration (days)
A	-	triangular OD = 4, MD = 5, PD = 7
B	A	normal $\mu = 7, \sigma = 2$
C	B, D	triangular OD = 9, MD = 11, PD = 14
D	-	normal $\mu = 8, \sigma = 1$
E	D	triangular OD = 6, MD = 7, PD = 8
F	C, E	if the starting date of F is less or equal 23 then normal $\mu = 9, \sigma = 1$ otherwise $\mu = 12, \sigma = 2$
G	C	normal $\mu = 15, \sigma = 3$ the duration of activity B and G are correlated with $\rho = -0,3$

This is a typical problem in project management. Everybody knows that it makes absolutely no sense to work with averages to apply CPM, but you can also not use PERT (see [9]) because using PERT means to use Beta distribution. In fact this is not that a big problem, because you can create Beta distributions that are quite similar to given triangular or normal distribution. But there is another disadvantage of PERT, because PERT assumes one unique critical path and calculates the distribution for this path. In practice, with the realization of the different activities you might get different critical paths.

PERT also assumes independency between the

different activities and as you can see, we have a negative correlation between activities B and G. With normal distributed random numbers this is no problem because out of two standard normal distributed random numbers  $z_1$  and  $z_2$  you can easily create random numbers  $r_1$  and  $r_2$  that follow two given normal distributions  $N(\mu_1, \sigma_1)$  and  $N(\mu_2, \sigma_2)$  with correlations  $\rho$  among them by using:

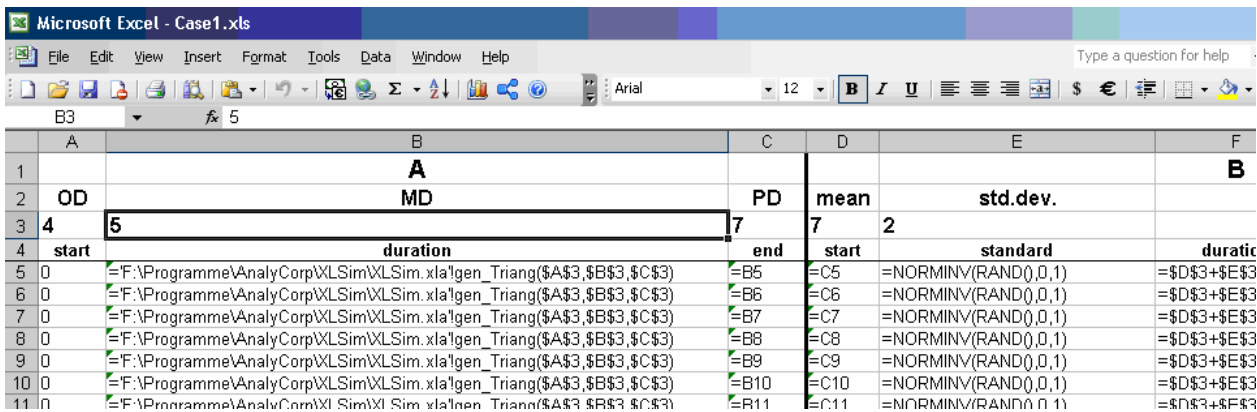
$$r_1 = \mu_1 + \sigma_1 \cdot z_1 \tag{1}$$

$$r_2 = \mu_2 + \sigma_2 \left( \rho \cdot z_1 + \sqrt{1 - \rho^2} \cdot z_2 \right) \tag{2}$$

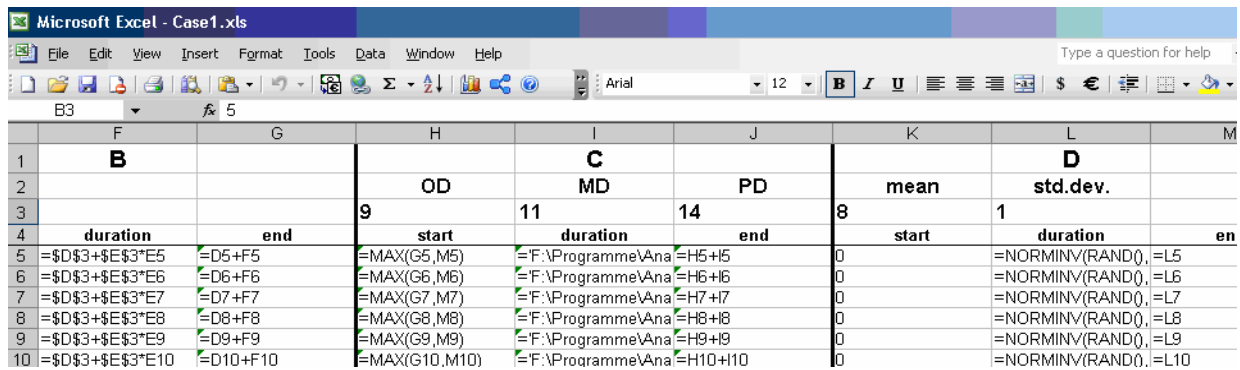
Another aspect that could not be handled with PERT is the additional condition for activity F. This is just an example and should show that within EXCEL a wide range of conditions of that type could easily be taken into account.

**SOLUTION CASE 1**

In fig. 4 – 6 you see several screenshot that show the solution of case 1. Here each row is one realization of the project and in fact you just have to formulate the problem once in one row. Afterwards you can copy it as often as you like to produce other independent realizations. In case 1 we decided to choose a number of 10,000 samples.



**Fig. 4 – Part 1 of case solution**



**Fig. 5 – Part 2 of case solution 1**

	T	U	V	W	X	Y
1			<b>G</b>		<b>end</b>	
2	<b>mean</b>	<b>std.dev.</b>	<b>corr. B</b>			
3	15	3	-0.3			
4	<b>start</b>	<b>standard</b>	<b>duration</b>	<b>end</b>		
5	=J5	=NORMINV(RAND(),I,=\$T\$3+\$U\$3*((\$V\$3*E5+(1-\$V\$3*2)*0.5*U5)		=T5+v5	=MAX(S5,W5)	=INT(2*X5+0.5)/2
6	=J6	=NORMINV(RAND(),I,=\$T\$3+\$U\$3*((\$V\$3*E6+(1-\$V\$3*2)*0.5*U6)		=T6+v6	=MAX(S6,W6)	=INT(2*X6+0.5)/2
7	=J7	=NORMINV(RAND(),I,=\$T\$3+\$U\$3*((\$V\$3*E7+(1-\$V\$3*2)*0.5*U7)		=T7+v7	=MAX(S7,W7)	=INT(2*X7+0.5)/2
8	=J8	=NORMINV(RAND(),I,=\$T\$3+\$U\$3*((\$V\$3*E8+(1-\$V\$3*2)*0.5*U8)		=T8+v8	=MAX(S8,W8)	=INT(2*X8+0.5)/2
9	=J9	=NORMINV(RAND(),I,=\$T\$3+\$U\$3*((\$V\$3*E9+(1-\$V\$3*2)*0.5*U9)		=T9+v9	=MAX(S9,W9)	=INT(2*X9+0.5)/2
10	=J10	=NORMINV(RAND(),I,=\$T\$3+\$U\$3*((\$V\$3*E10+(1-\$V\$3*2)*0.5*U10)		=T10+v10	=MAX(S10,W10)	=INT(2*X10+0.5)/2

Fig. 6 – Part 3 of case solution 1

In the end we get a distribution of the total time needed (fig. 7). By having the whole distribution, we are able to answer questions like:

- What is the most probable time to finish the project? (Answer: 39 days)
- Within which time are we able to finish the problem with a probability of 95 %? (Answer: 44 days)

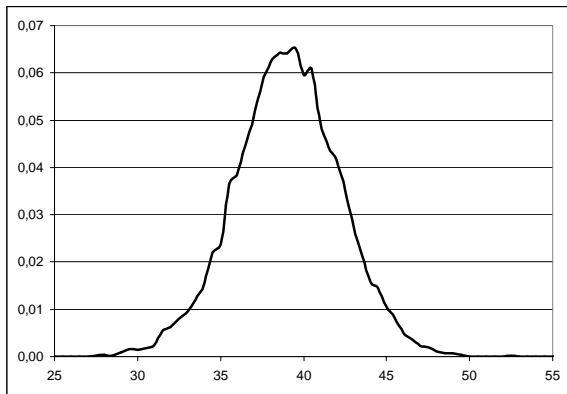


Fig. 7 – The density function of the duration in case 1

## CASE 2

In the second case we really do not need any distribution functions, because we only have binomial events. In a R&D project you have to overcome three different phases. In each phase several tasks have to be performed and for every task there is the probability to fail. Whereas in the first two phases at least one of the tasks needs a positive outcome to overcome the phase, in the third stage at least three of the four tasks got to be successful to overcome this step. The question here

of course is the probability that the whole project fails. The probabilities of the individual steps are given in fig. 8.

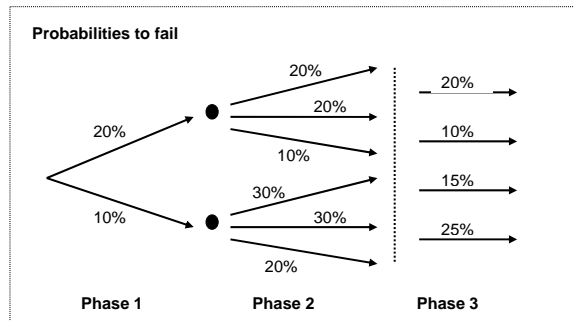


Fig. 8 – The three phases of the project of case 2

## SOLUTION CASE 2

In fig. 9 – 11 you see several screenshot that show the solution of case 2. It turns out that the probability of a success is about 84 %.

In this case we can model the solution by exclusive use of logical operators. The outcome of each phase is tested individually, then combined to test successful outcome of the whole project.

The trickier part lies within the outcome test of the second phase due to links of the phase activities to the previous' phase activities. Here, a successful outcome occurs when either activity A1 and one of the activities B1, B2, and B3 or activity A2 and one of B4, B5, and B6 are successful. Finally, the project's success depends on the positive outcome of all three project phases.

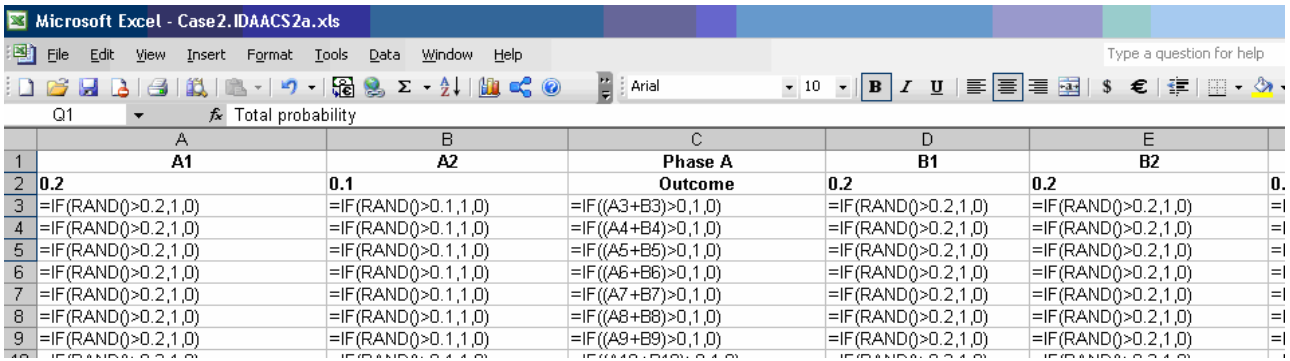


Fig. 9 – Part 1 of case solution 2

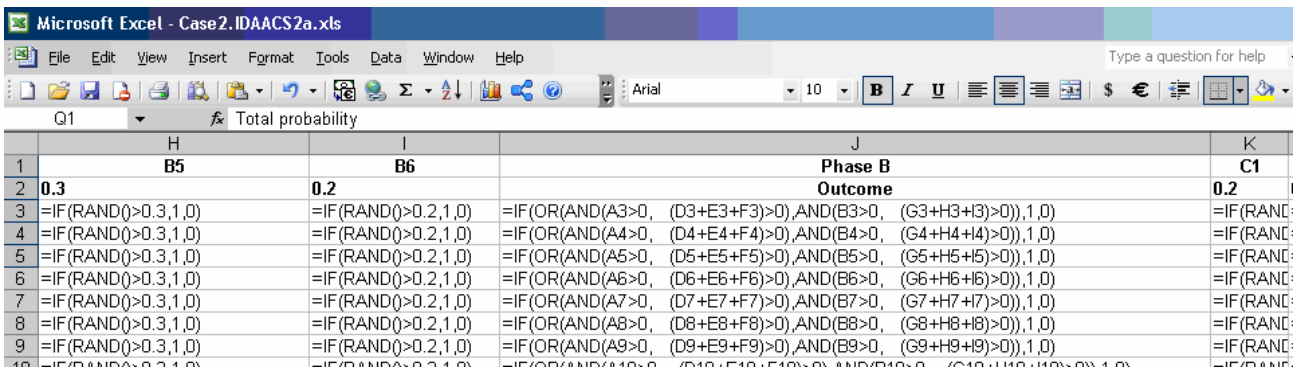


Fig. 10 – Part 2 of case solution 2

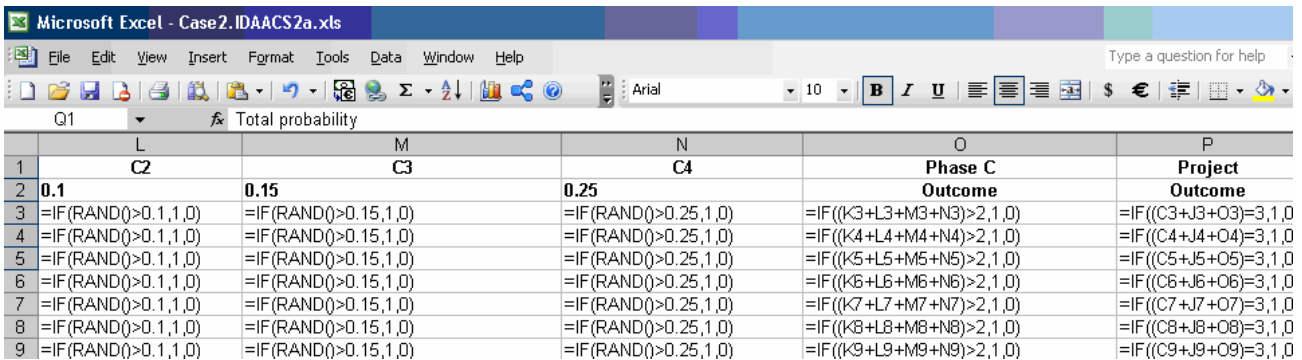


Fig. 11 – Part 3 of case solution 2

#### 4. SUMMARY AND REMARKS

Using Monte Carlo simulation with Excel offers a tool that enables also non-statisticians to model and simulate events, activities and outcomes of real life projects. Especially in the area of risk analysis we are fitted out with an extensive instrumentation for analyzing separate and aggregate risk impacts and probabilities. Amongst the major advantages underlined in this paper we count the relative cost-effective availability and spread in virtually every business and household on the globe of the Excel or equivalent software packages. Another advantage is that of overcoming some of the traditional challenges of classic analysis instruments such as PERT assuming unique critical paths, given distributions and independency of the individual

activities. As we showed in the two cases, it is very easy to implement given conditions between stochastic events just by using the internal condition functions within Excel.

Because all the Microsoft products, like Excel, offer you the opportunity to use VBA-macros, you also have the possibility to create your own special functions, your own menus, or whatever you like, to configure your individual model. This also gives you the opportunity to create libraries with pre-defined functions/macros that makes the use of this technique more efficient.

One of these libraries can for example try to handle the problem of correlations in a much wider sense than the one we showed here by using correlated normal distributions. One can consider here to create libraries for the Cholesky

decomposition of a given correlation matrix or the more sophisticated approach of Iman and Conover [13].

However, let there also be a message of warning to those that might fall into a “figure trap” and rely heavily on theoretical models and simulations in taking real world decisions. These have to be backed by intuition, common sense and leadership skills. The fabric of the project context is woven in an intricate pattern, many decisions require trade-offs and compromises, and the human influence factor is rarely quantifiable in a figures model. You always have to keep in mind that a mathematical model is always only a model of the reality that handles simplifications and reductions of the real world problem.

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