University of Twente
Industrial Engineering and Management

Decreasing the delay of Project X

- The Water Agency -

A.J. Stok
2020

DECREASING THE DELAY OF PROJECT X

Due to confidential reasons, the project name, its stakeholders, and the location of the project are removed in this public version and some figures, tables and words are censored.

A thesis presented in fulfillment of the requirements for the degree of
Bachelor of Science

Author:
A.J. Stok
s1942050
a.j.stok@student.utwente.nl

University of Twente

Drienerlolaan 5
7522 NB Enschede
The Netherlands

University supervisors:
dr. ir. W.J.A van Heeswijk
Faculty of Behavioural, Management and Social Sciences (BMS)

dr. ir. L.L.M. van der Wegen
Faculty of Behavioural, Management and Social Sciences (BMS)

The Water Agency

Olympia 2D
1213 NT Hilversum
The Netherlands

External supervisor:
G. van Essen
Managing Partner

October 2, 2020

Preface

Dear reader,

In front of you, I present you my bachelor thesis in the field of Industrial Engineering and Management. This thesis is the last step to complete this study at the University of Twente. In this project, I worked on behalf of The Water Agency, on the reduction of risks to minimise possible delays and attempt to have Project X finish on time. This study was carried out from February 2020 until October 2020.

This research project was mostly carried out from home due to COVID-19. The discussions with my university supervisors, Wouter van Heeswijk and Leo van der Wegen, were held online with Microsoft Teams and the meetings with my external supervisor, Gregor van Essen, were held in person or by phone. They helped me a lot when I had questions and gave me feedback that improved the research quality.

First of all, I would like to thank Gregor van Essen for being my external supervisor at The Water Agency and allowing to perform my thesis at the company. Thank you for your time, effort, thinking along, patience and feedback.

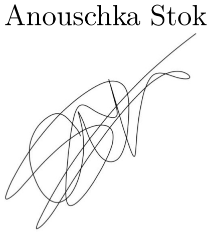
I would also like to thank my first supervisor Wouter van Heeswijk for providing detailed and useful feedback, which improved the quality of my bachelor thesis.

Furthermore, I would like to thank the stakeholders of the pilot project for their time to fill out the survey which was needed for this research. Without their cooperation, I could not have completed this research.

Lastly, I would like to thank my family, friends and boyfriend for their advice, support and involvement. They listened to my thought and comments about the study, and they helped me to come up with new ideas to improve my thesis.

I hope you will enjoy reading this report!

Anouschka Stok



Hilversum, October 2020

Management summary

Recently, city Z has been dealing with water and climate-related problems, most importantly: a surplus of water (causing flooding) during the monsoon season and a deficit of water (causing drought) during the dry season. A new innovative project has started to prevent these problems: Project X. The project will be implemented in one of the most vulnerable parts of city Z. Currently, there is a chance that the project will be cancelled or delayed, by COVID-19 and several risks the project faces.

The research goal of this thesis is to identify the risks of Project X and study their influence on the project duration. With this in mind, the research question of this study can be described, namely:

What risks should be prevented to finish Project X in time?

Research method
To answer the research question, a specific method is used. For this method, first the baseline schedule of the project was determined with the corresponding network diagram, then the risks were identified with the distributions of the activities. The pessimistic time estimation is the duration of an activity when all risks occur and the optimistic time estimation is the duration of an activity when none of the risks occur. These distributions were based on a survey sent to the stakeholders, in which the stakeholders filled out the optimistic, realistic and pessimistic time estimation of each activity. Additionally, they were asked to determine the top three risks of each activity with its corresponding severity. With this data, the risks per activity were determined. After the identifications of the risks, a Monte-Carlo simulation was performed to identify the critical activities and their corresponding risks. The activities were identified with sensitivity indices, these indices can be analysed to determine if an activity is or is not critical and if they influence the project. Furthermore a scenario analysis is made to identify five different scenarios of the project and to study if the duration of the project is reduced when risks are minimised. So per scenario, different risks were prevented to see the influence on the project duration.

Each activity is assumed to follow a beta PERT distribution (PERT is used when durations are uncertain and estimates the probability that the project finishes by the given deadline), which is dependent on three parameters (*min*, the optimistic time estimation, *mode*, the realistic time estimation, and *max*, the pessimistic time estimation) and its shape parameters (α and β). The identified risks are scaled with a risk matrix, which depends on the likelihood of occurrence of the risk and the severity of the risk.

Results and conclusion

Project X consists of twenty activities divided in seven phases. The phase B and phase D consist of sub activities, the phases are connected to each other through relationships. Some of these phases can only start when its predecessor is finished and some activities start at the same time. The implementation phase consists of three separate phases, each containing three sub phases: K, L and M.
There are three internal deadlines for this project: the elections for the mayoralty, starting on 01-11-2020, the World Water Day starting on 22-03-2021 and the end date of the project on 31-08-2021. The first deadline is the elections before which the phase B.2 must be finished. The second deadline is the World Water Day before which phase B.3 must be finished and the whole project must be finalised before the end date. In total 41 may risks affect the project. The risks are determined with the help of the main stakeholder by discussing the project. The most occurring risks are risks *f*, *g* and *s*. The risks can influence the activities in such a way that when all risks occur, the pessimistic duration of the activities happens. So these risks are included into the distribution of the activities.

According to the performed simulation, the optimistic estimation to carry out the project takes 406 working days, the most realistic estimation takes 520 working days and the pessimistic estimation takes 641 working days. The end date of the project for the optimistic duration is 23-08-2021, the end date of the project when the pessimistic duration occurs is 18-07-2022 and the expected end date of the project is 08-02-2022. The planned duration of the project is 412 working days, so the chance that the project finishes in time is really slim. Also, the deadlines for every estimation are not reached, only in the optimistic time estimation the end date deadline of the project is achieved. Therefore, different scenarios are studied to observe if the activity duration is reduced when risks are prevented. The scenarios studied are changes in the optimistic duration of the project, in the realistic duration and in the pessimistic duration, the fourth scenario is about preventing the risks that can occur the most and can have the most impact on the activities. The last scenario is based on the critical index of the activities, where risks are prevented for the activities with the highest critical index (CI). The adjusted optimistic, most realistic and pessimistic time estimations for every scenario are depicted in Table 1. In every scenario, none of the deadlines are reached.

Scenario 1 researched preventing risks for the optimistic time estimations, three risks can be prevented by the stakeholders for three phases. Scenario 2 prevents risks according to their realistic time estimation for also three phases. For this scenario seven risks can be prevented. Scenario 3 is based on the pessimistic time estimation of the simulation model. For this scenario four risks are prevented for three activities. Scenario 4 prevents the risks that have the most impact and occur often in all activities. From these risks, two risks can be prevented by stakeholders as they have an influence on these risks, these risks should be prevented for all activities. Scenario 5 focuses on the CI values of the activities. For the activities with the highest CI values (0.96), the risks are investigated and there are five activities with this CI value. There are 16 risks that occur in three or more activities. From these risks, seven risks can be prevented by the stakeholders.

Table 1: Number of working days of each scenario

Scenario	min	mode	max
1	441	531	626
2	444	512	601
3	453	514	593
4	433	525	594
5	451	505	580

Recommendations

The difference between the optimistic duration and pessimistic duration of the planned schedule is 235 working days, because of the large difference it is recommended to reduce this by following an investigated scenario of this research. In three scenarios the project duration is kept under 600 working days, namely, scenario 3, 4 and 5. Scenario 1 and 2 take 1.46 and 1.52 times as long as the planned duration when the pessimistic duration occurs, therefore these are not recommended. Scenario 3 consists of the worst optimistic time estimation compared to the other scenarios (453 working days), therefore this scenario is also not recommended. If the project manager decides to choose a scenario to follow, one of the other two scenarios is recommended, as in the worst case, the duration of the project is less than 600 working days and the optimistic duration is less than 453 working days. When the project manager wants to prevent the least number of risks compared to the other four scenarios, scenario 4 should be chosen. The realistic duration takes 525 working days, but the pessimistic duration (594 working days) is still below 600 working days. As this scenario prevents only two risks, these risks should be prevented for all activities. However, the optimistic duration of this scenario is the least of all the scenarios (433 working days). When the project manager wants to have a minimal realistic duration, scenario 5 is recommended as the pessimistic duration (580 working days) takes, just as the realistic duration (505 working days), the least amount of days compared to the other four scenarios. One thing to keep in mind is that, seven risks should be reduced for five activities in total, which is much work and many risks. Therefore the two scenarios are recommended, namely scenario 4 and 5.

Contents

List of Figures

List of Tables

Glossary

consortium partners organizations (companies, knowledge institutes, nongovernmental organizations) that, together with the lead partner carry out activities within the project, they have an interest in the continuation of the project. 1

critical path the longest path of dependent activities in the network from the start till the finish node. 6

directed arcs a graph in which the edges have a direction. 9

dynamic scheduling the process which presents real-time events, it analyses current status of schedules and automatically modifies the schedules with optimised measures (Fahmy et al., 2014). 3

makespan the time difference between the start and end of the activity. 9

risk averse the stakeholder chooses the preservation of capital over the potential for a higher-than-average return (Chen, 2020). 14

risk neutral the stakeholder is neither risk averse nor risk seeking. Any decision is not affected by the level of uncertainty of the outcomes. When two possible scenarios carry the same level of benefit, the risk neutral stakeholder will not be concerned if one scenario is riskier than the other (SCRUM, 2017). 14

risk seeking the stakeholder is willing to accept risk even if it delivers a marginal increase in return or benefit to the project (SCRUM, 2017). 14

sensitivity indices indices that can be analysed to determine if an activity is critical or not, so if they are influencing the project duration. 4, 49

stochastic random or involving chance or probability. 15

Chapter 1

Introduction

In this thesis, research has been conducted to obtain the Industrial Engineering and Management bachelor of Science degree. The research had a preparation period from February 2020 till April 2020, and the research was done from June 2020 till October 2020. The research was carried out at the company "The Water Agency". In this chapter, the company background is given (Section 1.1), followed by project background in Section 1.2, next the problem identification is given in Section 1.3, which has been supported by a problem cluster. Lastly, the research goal and method are described (Section 1.4 and Section 1.7). Additionally, the deliverables are discussed in Section 1.8 and in Section 1.6, the research questions are mentioned. To conclude the introduction, a reading guide is added.

1.1 Company background

This research was done within the framework of Project X and has been carried out on behalf of The Water Agency. Project X is further explained in Section 1.2. The Water Agency has its main office in Hilversum, the Netherlands and several other office's in the Asia-Pacific region: Myanmar, Indonesia, Australia and Vietnam. They have the vision and mission that water is a valued and shared force of life for all people in Asia-Pacific (*About The Water Agency*, n.d.). This mission is achieved by setting up local *Water Hubs*, which are places where education, knowledge, business and communication come together. As such, it is a place that connects, engages and inspires people and organisations to collaborate, share knowledge and create solutions that address the regions most pressing water issues.

1.2 Project background

Due to confidential issues, this section is removed.

1.2.1 Stakeholders

When conducting research, it is important to know who is involved in the project and how they influence the project. In the project, there is a consortium of Dutch companies that is responsible for designing, planning and executing the pilot project, in the stakeholders table, these members are the consortium partners.

Due to confidential issues, the table of the stakeholders is removed.

1.3 Problem identification

Due to confidential issues, this section is removed.

1.3.1 Problem cluster

A problem cluster is used to find out the connections between different problems (Heerkens & van Winden, 2017). To come up with the problems, different talks with the stakeholders took place to make sure that everything is included. The problem cluster of this project is depicted in Figure 1.1. With this problem cluster, the research problem can be identified. This research concerns the risks that involve the project; this is depicted with the coloured square in the problem cluster.

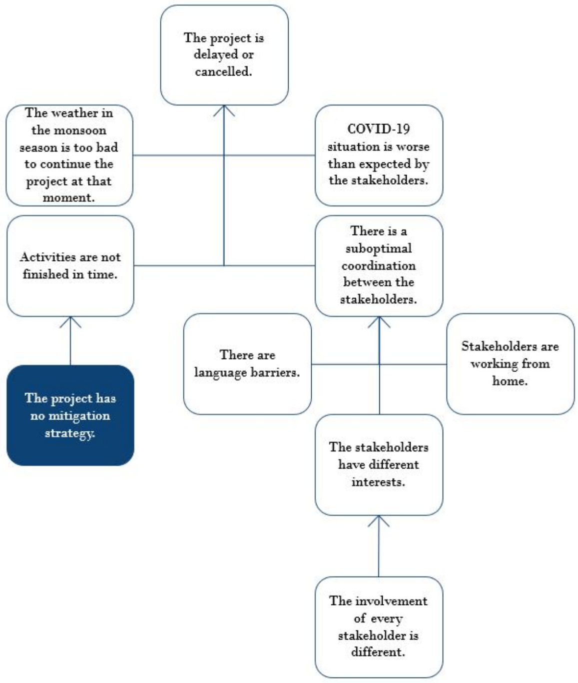


Figure 1.1: Problem cluster

In Figure 1.1, the main problem is depicted, which is that the project is delayed or cancelled. Possible causes are: the unexpected COVID-19 virus, the bad weather conditions that can arise during the monsoon season, no optimal coordination between the stakeholders and delays in the execution of the activities.

The stakeholders have different interests in the project, there are language barriers, due to different nationalities and expertises, and stakeholders are working from home. These three problems result in a suboptimal coordination between the stakeholders. The bigger companies do not have a problem when there is a time delay, because they have enough capacity (resources) to continue the project when there is a substantial amount of delay. Therefore, they are more focused on the quality of the project. The smaller companies will face more consequences when the delay increases as they do not have sufficient provisions when there is a substantial amount of delay. Each stakeholder has its own task to perform, this means that they are seeing the project in a different way than another stakeholder. Due to working from home, stakeholders are dependent of the internet. It is also easier to see one other in real life when communicating, which is not possible at this moment.

On the left side of the problem cluster, one potential problem is that activities are not finished in time. This can be caused by not having a mitigation strategy, which means that there is no strategy for decreasing the delay of the project. So no risk analysis is made for this project. Therefore, it is difficult to foresee future problems that can result in a possible project delay. The risks of the project and their influences are not determined yet. At this moment, the stakeholders do not know the risks that concern the project and how these risks influence the project. With a strategy, different risks can be prevented to prevent delay of the project.

1.3.2 Core problem

In the problem cluster, there are many issues that the project is facing. Two potential core problems cannot be solved, the monsoon season and the COVID-19 situation. Therefore, only two other potential core problems remain, namely: activities are not finished in time and there is a suboptimal coordination between the stakeholders. These sub problems are caused by several other problems, which can be seen in Figure 1.1. The most relevant subject to change is that activities are not finished in time. This is caused by not having a mitigation strategy. The mitigation strategy can have the most influence when the delays are prevented. This is also the most important subject of them all because a risk analysis can prevent future problems by implementing solutions to these risks and with a risk analysis preventing different risks can be researched. This can cause different strategies that can be implemented. Therefore, the core problem is that the project has no mitigation strategy, and as such, a risk analysis must be made to take all the risks into account.

The norm of the core problem is to have a risk analysis, while in reality, there is no risk analysis at this moment in time. The core problem for this research will therefore be:

"What risks should be prevented to finish Project X in time?"

1.4 Research goal

According to the project plan of the project, the interventions of the pilot project need to be finished by September 2021 with a critical, intermediate milestone in November 2020 to demonstrate significant and tangible results to the Chief Minister and Mayor of the government. At the same time, the project is facing serious potential impact from both the upcoming national elections in county Y (8 November) and the spread of COVID-19 which may endanger both the intermediate and final milestones. Therefore, the goal of this research is to identify the risks of the project and monitor the impact of the risks on the project so their influence on the project is known. With these monitored influences of the risks, risks can be prevented to see if the project can finish in time. When a risk has an impact on the duration of the project, the prevention of this risks will be simulated and with the help of a simulation the impact of the risks will be simulated in different scenarios.

1.5 Theoretical framework

This research is based on the four steps of Vanhoucke (2013) and existing literature used in practise. These steps help to create a timeline and intervene in the existing risks of the project. His book deals with project management and dynamic scheduling; he creates an approach to identify the risks and advises the project manager on how to deal with and control the existing risks. With these steps, it is possible to identify the risks and the project schedule, which will be necessary when creating a risk analysis. From this risk analysis, a scenario analysis was developed to see if preventing certain risks will influence the total project duration. The scenario analysis is supported by the Monte-Carlo simulation and the sensitivity index CI.These four steps are depicted in Figure 1.2.

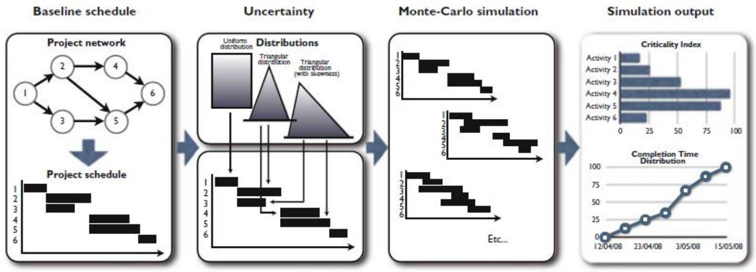


Figure 1.2: Four steps to create a risk analysis (Vanhoucke, 2013)

Literature and mathematical formulas support each step, for example, when creating a critical path. So the four steps in words are:

1. Creating a baseline schedule with a network diagram.
2. Identifying the risks and the probability distributions of the activities.
3. Creating a Monte-Carlo simulation to get an overview of the duration of the project.
4. Identifying the simulation outputs with sensitivity indices.

This theory is implemented in the research and knowledge questions that support the main research question. These questions can be found in Section 1.6.

1.6 Research questions

With the research goal in mind, the research question that is central during this research is:

"What risks should be prevented to finish Project X in time?"

To answer the research question, several other research and knowledge questions should be answered first. These questions are based on the problem-solving method and their deliverables.

1. Which method can be used to create a risk analysis?
   - 1.1 What is a baseline schedule?
   - 1.2 What methods can be used to schedule activities?
   - 1.3 How can risks be defined?
   - 1.4 What method can be used to create a simulation model?
   - 1.5 How are the simulation outputs measured?
2. What is the current schedule of Project X?
   - 2.1 What activities need to be scheduled?
   - 2.2 What are the milestones of the project?
   - 2.3 What is the project's network?

3. What risks influence the duration of the project?

   3.1 What are the risks of the project?

   3.2 What is the impact of the involved risks?

4. What solutions can be created to prevent the risks of Project X?

   4.1 What solutions are there to prevent the risks of an activity?

   4.2 How much do these solutions influence the end date of the project?

1.7 Research method

In this section, the research method is discussed. The research method is based on the research questions of this research. This involves the methodology used in this research, the data gathering method with its variables and data analysis method, and how the validity and reliability of this research can be assured. The data method is created with the research questions of Section 1.6 in mind.

1.7.1 Methodology

According to Heerkens & van Winden (2017) there are seven phases of a problem-solving method, namely:

1. Defining the problem
2. Formulating the approach
3. Analysing the problem
4. Formulating (alternative) solutions
5. Choosing a solution
6. Implementing the solution
7. Evaluating the solution

This managerial problem-solving method has been used in this study to solve the corresponding action problem and as such, it is important to follow these seven steps.

1.7.2 Data gathering method

According to Cooper & Schindler (2014) *"research design is an activity- and time-based plan, a plan based on the research questions, a guide for selecting sources and types of information, a framework for specifying the relationships among the variables and a procedural for every research activity"*. There are three kinds of studies, an analytical study, a descriptive study and a causal study (Cooper & Schindler, 2014). This research is an analytical study, as this research investigates hypothesised relationships between risk factors and the outcome. It identifies and quantifies associations, tests hypotheses and identifies causes, exactly what happens in this research (Aggarwa & Ranganathan, 2019). Explanatory research develops concepts more clearly, establishes priorities, develops operational definitions and improves the final research design.

For this research, the quantitative method has been used (e.g. conducting information from the stakeholders by surveys). The stakeholders are the focus group of the research and the goal of the survey is to identify the impacts of the risks and the durations of the activities. Furthermore, secondary data will be used, namely, data from other articles. The research starts with the data of the project to see what information is present and what information is still needed.

Variables

The key variables of this research are the risks. The main variable needs to be operationalisable, risk can be measured in terms of risk ratings. These ratings are dependent on the likelihood of occurance of the risk and the severity of the risk.

One index will used to identify the simulated duration of the activities. These key variable is the CI, critical index, which is linked to the critical path method (Kandaswamy, 2001). When this index is identified, it can be very useful to the company to see whether or not they need to intervene in an activity, to prevent risk, or make the risk smaller, so the chance that the risk will happen is minimised. The criticality index (CI) *"measures the probability that an activity is on the critical path"*. (Vanhoucke, 2016)

Data analysis method

The surveys are a quantitative research method. Answers from this quantitative research model can be obtained by following four steps: getting familiar with the data, revisiting research objectives, developing a framework and identifying patterns and connections between the surveys (Bhatia, 2018).

In this thesis, a literature study was conducted to answer the knowledge questions (Section 1.6). These studies are qualitative research methods because different articles were analysed to see what they have in common.

The Monte-Carlo simulation will calculate the effect of the unpredictable variables with a specific factor. Furthermore, it will help to predict the risks, which is needed to make a risk analysis. The simulation will use random numbers and data to stage a variety of possible outcomes to a situation, by testing the possibilities, the effect of the random variables on the project can be understood (Liberty, 2019). Therefore the simulation is a quantitative research method.

1.7.3 Validity and reliability

Validity and reliability are essential in research. According to Middleton (2019), validity concerns the accuracy of a measurement and reliability entails if similar results are achieved when using the same method and circumstances.

Validity must be considered in the early stages of the research (Middleton, 2019), it is about how the data is collected. Reliable and valid literature must be found to have a basis for the research and survey. For the questionnaire, an appropriate method of measurements needs to be chosen. This survey needs to have a basis which is standardised and is considered reliable and valid. For an accurate and reliable risk analysis, it is essential to get as much information as needed about the activities and risks. The inputs, from the Monte-Carlo simulation, are obtained from the stakeholders in a questionnaire form and are therefore less reliable.

Reliability must be considered throughout the data collection process (Middleton, 2019). Reliability of the research can be guaranteed by applying different methods consistently and standardising the conditions of the research.

1.8 Deliverables

Surveys from the stakeholders were conducted to gather information about the current schedule and risks. Additionally, a literature study on how to perform a risk analysis and already existing solutions was carried out. Furthermore, the research delivers a baseline schedule, an analysis about the risks and the sensitivity results. The research is a simulation model, so a Monte-Carlo simulation was developed to support the study. To conclude the research, advice on which scenario to implement in the project is given.

1.9 Reading guide

In this research, the core problem *"What risks should be prevented to finish Project X in time?"* is answered. To investigate this problem, first a literature study was done in Chapter 2 to determine the method necessary to perform the research. In this chapter baseline scheduling is discussed, as well as network diagrams, risks, Monte-Carlo simulation, simulation output and an action threshold.

Chapter 3 discusses the current situation of the project. It is important to determine the schedule of the project and its risks to investigate the core problem. A survey is also introduced in this chapter. The survey will help to understand the importance of the risks and how the risks are influencing the activities. With the help of the respondents, the optimistic, pessimistic and realistic time estimations of the activities are determined.

Chapter 4 discusses the simulation model to see if activities are deviating from the planned durations and the planned schedule. Here the scenario analysis is also introduced to investigate several scenarios.

The results of the research are explained in Chapter 5. This entails the results of the survey, the Monte-Carlo simulation and the results of the scenario analysis.

The research is concluded in Chapter 7 and recommendations to decrease or prevent the delay of the project are suggested. The report is closed with an Appendix.

Chapter 2

Literature review

Completing a project within the given time frame is not an easy task. Scheduling a project is the first step to indicate the projects end date. For this timeline, a baseline schedule needs to be created. This is the basic timeline of the project. In this chapter, the research question *which method can be used to create a risk analysis?* and its sub-questions *what is a baseline schedule*, *what methods can be used to schedule activities*, *how can risks be defined*, *what method can be used to create a simulation model* and *how are the simulation outputs measured* are answered. Section 2.1 explains how to create a baseline schedule. In Section 2.2, the critical path and the network diagrams which are used to create the timeline with dependent activities are described. Furthermore, the identification of the risks (Section 2.3) are mentioned, as well as the distribution of the risks (beta distribution).

To identify the most critical activity (the activity that is the most deviated), a Monte-Carlo simulation will be created. This method is explained in Section 2.4. One index from the simulation output (Section 2.5) is used to identify the most critical activity.

2.1 Baseline scheduling

Completing the project within the constraints of the cost, quality, scope, time, resources, and risks determine the success of a project (Project Management Institute, 2013). Success refers to the last baseline that is approved by the stakeholders, a baseline that takes into account the possible risks that can occur. When making a risk analysis, baseline scheduling is important. According to the Oxford dictionary (Oxford University, 2020), a baseline is *"a line or measurement that is used as a starting point when comparing facts"*. So when making a risk analysis, the baseline is the basic schedule made at the beginning of the project, when the project is not started yet. With this baseline, a comparison is made when risks are occurring, and possible solutions can be implemented to prevent these risks. There can be different kinds of baselines, e.g., the scope baseline, cost baseline, and schedule baseline (Project Management Institute, 2013). For each baseline, different researches can be done. A baseline schedule is the approved version of the scheduled model, which is the basis for a comparison to the actual results. This baseline is accepted and approved by the appropriate stakeholders with its start dates and baseline finish date.

When starting a project, it requires a project-planning phase that consists of a baseline schedule and risk analysis (Votto et al., 2020). This step includes the project network with the activities, dependencies, and durations, which serves as a basis for this schedule. Although it is doubtful that every activity will proceed according to the plan, the baseline schedule plays a central role in making a risk analysis. During project execution, performance indicators can be monitored to detect deviations from the baseline schedule. The baseline schedule measures deviations and takes necessary actions to correct the deviations as early as possible to ensure that the project is completed on time. When an abnormal behaviour occurs concerning the initial schedule, this must be detected and interpreted to make any changes.

Most of the time, there is an evaluation of the actual project performance in comparison to the baseline schedule, which can track the progress of the project (Assaad et al., 2020). So, a well-intentioned level of protection against the risks could be reached by planning a baseline schedule (Yeganeh & Zegordi, 2019). There is a challenge for project managers to minimise the makespan of the project while satisfying the project constraints. A good baseline schedule can prevent many delays, as well as more costs and time overrun. The risk analysis identifies the major risk factors and can see if risks influence the baseline schedule. Using identified risk factors, their probability of occurrence and impact, a flexible baseline project schedule can be created. This schedule is sufficiently protected against the unexpected disruptions that may occur during project execution and that threatens the due date performance.

2.2 Network diagrams

A project schedule can be classified into three sections, the Gantt chart, the milestone chart, and the project schedule network diagram (Project Management Institute, 2013). A Gantt chart shows in detail the tasks of the project (O'Cull et al., 2011). The left side of the chart displays the tasks; the right side displays a bar chart. This bar chart shows the information about the tasks on a timescale graphically. The milestone chart shows the different planned milestones in a graph and has the same settings as the Gantt chart.

Nodes and arcs define a network diagram; in this thesis directed arcs are used. Nodes are the vertices of a graph, set of points. According to Winston (2004), "*an arc consists of an ordered pair of vertices and represents a possible direction of motion that may occur between vertices*". Motion is possible from node i to node j. This is defined as (i, j) where node i is the initial node, and node j is the terminal node. There are two kinds of activity network diagrams, the activity on arc (AOA) and the activity on node (AON) network chart (Yang & Wang, 2010). AON is a technique where the node represents a job, and the arrow represents the relation between the two jobs. The arrow should be presented from left to right (this is the job direction). An AON network, compared with an AOA network, has fewer nodes, is clear and easy to draw. The AOA network is slightly different. The arrow represents a job, the end (flat side) represents the beginning of the job, and the head (the barb) represents the end of a job. Two methods can be applied to both diagrams: CPM (Critical Path Method) and PERT (Program Evaluation and Review Technique) (Winston, 2004). These models can be used in scheduling large complex projects that consist of many activities, just like Project X.

CPM is used to determine how long activities in the project can be postponed without delaying the project. PERT is used when durations are uncertain and estimates the probability that the project finishes by the given deadline. To apply CPM and PERT, a list of activities (jobs on the arcs) must be present. The project is completed when all activities are finished. Some activities have predecessors, so activities that must be completed before the next activity can start.

The critical path is the longest path of dependent activities in the network from the start node until the finish node. A delay in the critical path causes a delay in the completion of the whole project. Therefore it is advisable to monitor the critical activities closely. Both the CPM method and the PERT method are based on Winston (2004). The CPM method is explained in Section 2.2.2, and the PERT method is explained in Section 2.2.3. First, the relationships between different activities are explained, so these methods can be applied in both the PERT and CPM method.

2.2.1 Relationships

Activities can be connected in different ways, this sections discusses the connections/relationships. In a network diagram, there are different relationships between the scheduled activities. There are time lags between different relationships, different types, and a minimal and maximal which influence the relationships between activities. These need to be implemented in the networks. There are also milestones in a network diagram. These milestones need to be finished on the exact date as planned. So it is of great importance to make sure that the activities are not delayed and that relationships between activities and milestones are identified.

Time lags

Time lags are the times that can occur between activities. For example, FS_{ij} means finish to start, so activity j can only start after activity i is finished (Vanhoucke, 2013). A zero time lag means that j can immediately start when activity i is finished. This is denoted by FS_{ij}. When there is a time lag, $n > 0$, activity j can start n periods after activity i is finished. This is a non zero time lag and is denoted as $FS_{ij} = n$. These time lags can be implemented in different types of relationships. An example of a time lag is when an activity is starting one month after the start of an other activity. The activity is for example the implementation of different interventions. Monitoring interventions can start already when the first intervention is implemented, this means that the activity of implementing different interventions does not have to be finished when starting the monitoring activity. Therefore the monitoring activity can start when the first intervention is implemented, so for example, one month after the start of the intervention activity.

Links between activities

There are four kinds of relationships in a network diagram: the SS (start-to-start) relationship, the FF (finish-to-finish) relationship, the FS (finish-to-start) relationship and the SF (start-to-finish) relationship (Vanhoucke, 2013).

$SS_{ij} = n$ means that activity j can start n time periods after the start of activity i. This relationship can also be zero, so the activities are starting at the same time.

$FF_{ij} = n$ means that activity j can only finish n periods after activity i is finished. Just like the SS relationship, the FF can be zero, so activity j can finish at the same time as when activity i is finished.

$FS_{ij} = n$ means that activity j can only start n periods after the finish of activity i. This relationship can also be zero, which means that j can be started at the same time when activity i finishes. $SF_{ij} = n$ means that activity j can only finish n periods after the start of activity i. This relationship can also be zero, which means that j can be finished at the same time as when activity i starts. These relationships are depicted in Figure 2.1.

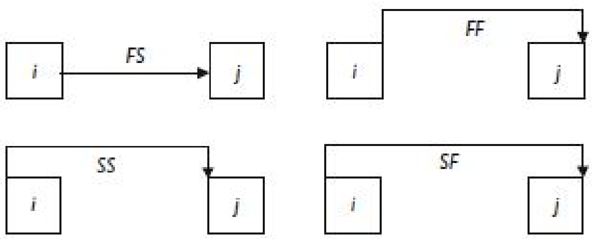


Figure 2.1: Relationships of network diagrams (Vanhoucke, 2013).

Minimal/Maximal

All the relationships explained above are all part of the minimum requirements. The minimum relationship is denoted as $FS_{ij}^{-} = n$ (Vanhoucke, 2013). This means that activity j can start n or more periods after activity i is finished. When there is a maximum relationship between activities, this is denoted as $FS_{ij}^{+} = n$. This relationship is the exact opposite of the minimum relationship and means that activity j can start n or fewer periods after activity i is finished.

The relationships are connected to the activities of the schedule. When a network of activities are created and there is a delay in one of the activities, the next activity has to start later than planned.

2.2.2 CPM

The goal of CPM is to know how long activities can be delayed without delaying the total time of the project (Winston, 2004). The free float measures the amount of time that a scheduled activity can be delayed without delaying the early start date of an immediate successor within the network path. Free float is denoted as $FL(i, j)$ where i is the first node and j is the following node.

It is important to determine the early event time and late event time of the activities when finding the critical path. The early event time of node i ($ET(i)$) is the earliest time that an activity/event (corresponding to node i) can occur. The late event time of node i ($LT(i)$) is the latest time the activity/event (corresponding to node i) can occur, without delaying the end time of the project.

$ET(j)$ is the earliest time an activity can start. To calculate $ET(j)$ the predecessors of j should be known, these are presented as B_j. So B_j is the set of nodes that are directly preceding j. To compute $ET(j)$ (for $j > i$) one or more $ET(i)$ should be known. A formula of the $ET(j)$ is shown in Equation 2.1, t_{ij} is the duration of activity (i, j). When $j = 1$, $ET(1) = 0$ because node 1 represents the start of the project.

$$ET(j) = \max_{i \in B_j}(ET(i) + t_{ij}) \tag{2.1}$$

$LT(i)$ computes the latest time at which an event (i) can start without delaying the whole project. For this equation the latest time of successors of i should be known ($j > i$). Equation 2.2 shows the formula of $LT(i)$. Where A_i represents the set of nodes directly succeeding i.

$$LT(i) = \min_{j \in A_i}(LT(j) - t_{ij}) \tag{2.2}$$

To find the critical path, with its critical activities, the total float of an activity should be zero. When the total float is zero, any delay in an activity will cause a delay in the total time of the project. The Total Float ($TF(i, j)$) "*is the amount by which the starting time of activity (i, j) could be delayed beyond its earliest possible starting time without delaying the completion of the project (assuming no other activities are delayed)*" (Winston, 2004). In other words, the total float is the amount of which an activity duration can be increased without delaying the project. The corresponding formula is shown in Equation 2.3, when $TF = 0$, the activity is critical.

$$TF(i, j) = LT(j) - ET(i) - t_{ij} \tag{2.3}$$

2.2.3 PERT

PERT models the duration of activities as a random variable (Winston, 2004; Vanhoucke, 2013; Dan Reid & Sanders, 2010). The duration of activities is estimated by someone who is familiar with the activity and has enough knowledge about the characteristics. The PERT method is characterised by three parameters:

$$\begin{aligned} min &= \text{optimistic time estimation, perfect path, shortest time.} \\ mode &= \text{realistic time estimation, most likely value for activity durations.} \\ max &= \text{pessimistic time estimation, worst case path, longest time.} \end{aligned}$$

The PERT model follows a beta distribution (Conant, 2018), which has different shape parameters (α and β) depicted in Equation 2.4 and Equation 2.5. The influence of the shape parameters is depicted in Figure 2.5.

$$\alpha = \frac{2(b+4m-5a)}{3(b-a)}\left[1+4\frac{(m-1)(b-m)}{(b-a)^2}\right] \tag{2.4}$$

$$\beta = \frac{2(5b-4m-a)}{3(b-a)}\left[1+4\frac{(m-1)(b-m)}{(b-a)^2}\right] \tag{2.5}$$

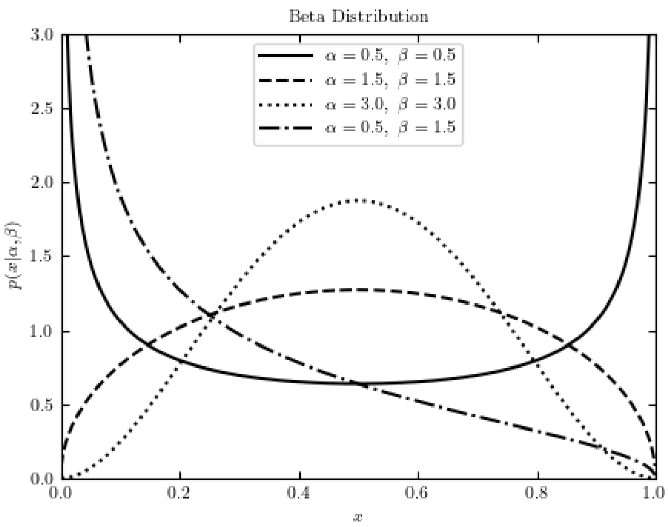


Figure 2.2: The influence of the shape parameters on the beta distribution, (*Statistics, Data Mining, and Machine Learning in Astronomy: A Practical Python Guide for the Analysis of Survey Data*, 2014)

The formula of the beta PERT distribution is displayed in Formula 2.6, where $f(x)$ is the probability density $p(x|\alpha,\beta,a,b)$ (Hahn, 2008; Hajdu & Bokor, 2014).

$$f(x) = \begin{cases} \dfrac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} * \dfrac{(x-a)^{\alpha-1}(b-x)^{\beta-1}}{(b-a)^{\alpha+\beta-1}} & \text{if } a \le x \le b \quad \text{and} \quad \alpha,\beta > 0 \\ 0 & \text{otherwise} \end{cases} \tag{2.6}$$

The expected time for an activity is given in Formula 2.7, the standard deviation of an activity is given in Formula 2.8 and the variation of the time of the activity is given in Formula 2.9.

$$\mathbb{E}(T_{i,j}) = \frac{a + 4m + b}{6} \tag{2.7}$$

$$\sigma_{T_{i,j}} = \frac{b - a}{6} \tag{2.8}$$

$$var(T_{i,j}) = \frac{(b - a)^2}{36} \tag{2.9}$$

The critical path (CP) can be found according to these formulas. PERT requires an assumption that all durations of the activities are independent. So when you want to know the expected duration of the CP and the variance of the CP this can be calculated by the formulas below. L represents the activities that are a part of the critical path.

$$CP = \sum_{(i,j) \in \mathrm{L}} T_{i,j} \tag{2.10}$$

$$\mathbb{E}(CP) = \sum_{(i,j) \in \mathrm{L}} \mathbb{E}(T_{i,j)} \tag{2.11}$$

$$var(CP) = \sum_{(i,j) \in \mathrm{L}} var(T_{i,j}) \tag{2.12}$$

It is possible to determine the chance that a project can be finished in x days, if the project follows a normal distribution. The formula to determine the likelihood is given in Formula 2.13, where $\sigma = \sqrt{var(CP)}$. The z-value in the second line, corresponds to a probability. The z-values are found in Appendix A. The corresponding percentage can be found by knowing the first and second decimal of the z-value. The first decimal is on the y-axis, the second decimal of the z-value is on the x-axis.

$$\begin{aligned} \mathbb{P}[T \leq x] =& \mathbb{P}[CP \leq x] = \mathbb{P}\left[\frac{CP - \mathbb{E}(CP)}{\sigma_{CP}} \leq \frac{x - \mathbb{E}(CP)}{\sigma_{CP}}\right] \\ =& \mathbb{P}\left[z \leq \frac{x - \mathbb{E}(CP)}{\sigma_{CP}}\right] \end{aligned} \tag{2.13}$$

2.3 Risks

The first step, according to Vanhoucke (2013), was to create a baseline schedule with a network diagram. The second step is to make a risk analysis to identify the risks and their probability distributions. Here the uncertainty is translated in duration. Risks can have an upside and downside effect that can be predicted (Raftery, 1994). The seriousness of a risk and whether or not to keep a close eye to a risks can be defined with a risk rating. This risk rating rates the risks on their likelihood of occurrence and their severity. It is defined as as $Risk\, rating = likelihood\, of\, occurrence * severity\, of\, the\, risk$, in Figure 2.3 a risk matrix is depicted. In this risk matrix, every risk has his own degree of likelihood and severity, and with this degree, it is possible to see how urgent a risk is.

An risk can have influence on the duration of an activity and each activity can have different risks. When all these risks are occurring they are causing the pessimistic scenario mentioned in Section 2.2.3, when none of them occur, there is an optimistic scenario.

In this thesis, risk can be found as a combination of hard data and opinions of experts. This makes the decision a well-informed decision, for a well-informed decision, all the available information is used, both objective and subjective. A basic understanding of probability and distribution functions is necessary; they allow the project manager to better estimate the effects of the risks on the activities (Vanhoucke, 2013).

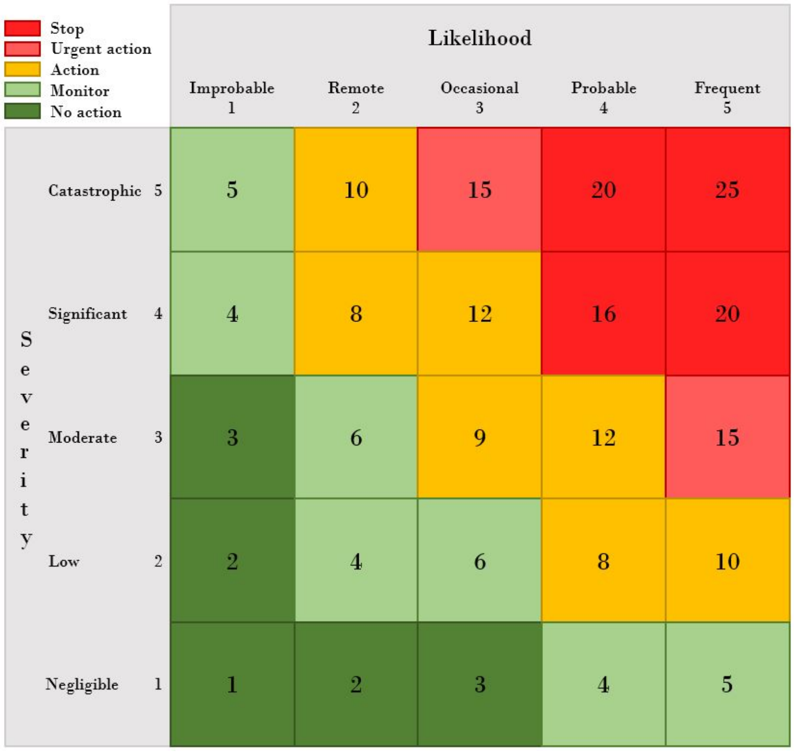


Figure 2.3: Risk matrix (Kaya et al., 2019)

When making a formal risk analysis, all risks should be considered. There are three kinds of project managers, risk neutral project managers, risk seeking project managers, and risk averse project managers (SCRUM, 2017).

As described in section 2.2.3, the optimistic, realistic, and pessimistic time estimation of the activities must be known, and the critical path is estimated. The critical path must be followed closely to avoid risks. With the beta distribution, the estimated times can be calculated. The duration distribution can be skewed to the left, skewed to the right, or symmetric (in that case $mode - min = max - mode$). When $min = max = 1$, the duration is uniformly distributed (Ma, 2016). These are the possible beta distributions, which are depicted in Figure 2.4.

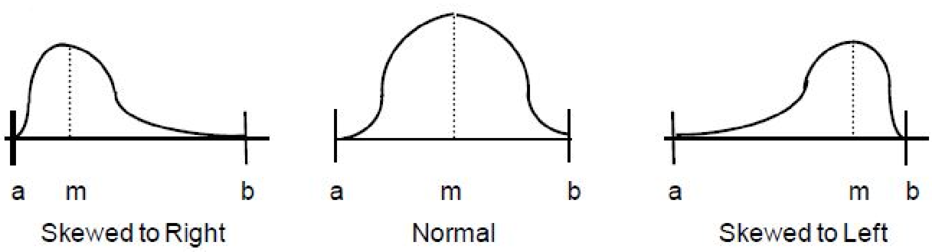


Figure 2.4: Examples of Beta distributions (De Marco, 2011), where $a = min$, $m = mode$ and $b = max$.

The tree point estimates (min, $mode$ and max) can be used to predict whether or not the distribution of the activity is skewed to the left, right, or normal (Vanhoucke, 2013). When the activity distribution is skewed to the right, $mode - min < max - mode$. When the activity distribution is skewed to the left, it is the exact opposite: $mode - min > max - mode$.

There are different types of risks (Ghosh & Jintanapakanont, 2004), which should be taken into account when identifying the risks of the pilot project. The categories of risks are:

- Financial and economic risk
- Operational risk
- Safety and social risk
- Design risk
- Force majeure risk

Financial and economic risks are risks that involve the money within the project. Financial risk can be the failure to pay a supplier, whereas economic risk concerns the loss for a business (LexisNexis, n.d.). Economic risks concern interest rates, minimum wages, market prices, taxes, duty rates and cost of materials, which can be higher than expected. Financial risk involves unavailability of funds, the financial failure of a contractor or inflation for example. These examples can have an influence on the duration of the project because they all have an impact on the available money within the project. Operational risk is uncertainties a company can face in its day-to-day business activities (Segal, 2019). Operational risk focuses on how things are being accomplished within the organisation, not what is produced within the industry. Examples of operational risks are system outage, labour productivity and equipment productivity. Safety and social risk are risks concerning the environment and the workers working on the project. Risks in this field are accidents, ecological constraints, damage to persons or property, pollution and safety rules and public consultancy (Ghosh & Jintanapakanont, 2004). Design risk is about flaws in the design phase of a project. Design risks concern scope of work definition, inadequate specification, conflict of document and design changes. Force majeure risk is the risk that there is a prolonged interruption of operations due to fire, flood, storm, or another factor beyond the control of the manager and/or stakeholders, so, for instance, unexpected circumstances like war (Dictionary, n.d.). All these categories are necessary to take into account when risks are identified for the project.

2.4 Monte-Carlo simulation

According to Vanhoucke (2013), the third step is to come up with a Monte-Carlo simulation. A Monte-Carlo simulation is a computer simulation which describes the behaviour of a system over an extended period and incorporates stochastic/random variability into the model (Bonate, 2001). It is a mathematical model of a system, that is used to make decisions, understand the (complex) system of the project and to solve problems. The simulation is an abstraction of the real system containing inputs and outputs. The Monte-Carlo simulation repeatedly simulates the given model. For each simulation, a different random set of values (inputs) from the sampling distribution of the model is selected. From these inputs, different possible outcomes are used to select a possible solution for a given output. A Monte-Carlo simulation runs the generated duration for each project activity given its predefined distribution and thus, uncertainty profile (Vanhoucke, 2013). The simulation validates the impact of the changes in the project outcome. It is a guide for the project manager in selecting the best performing forecasting techniques for projects in progress. There are three steps for executing the simulation; these steps are depicted in Figure 2.5.

1. Random number generation

2. Generate the cumulative distribution function of the duration

3. Based on the new duration of the cumulative distribution, add the new duration of the activities into the baseline schedule

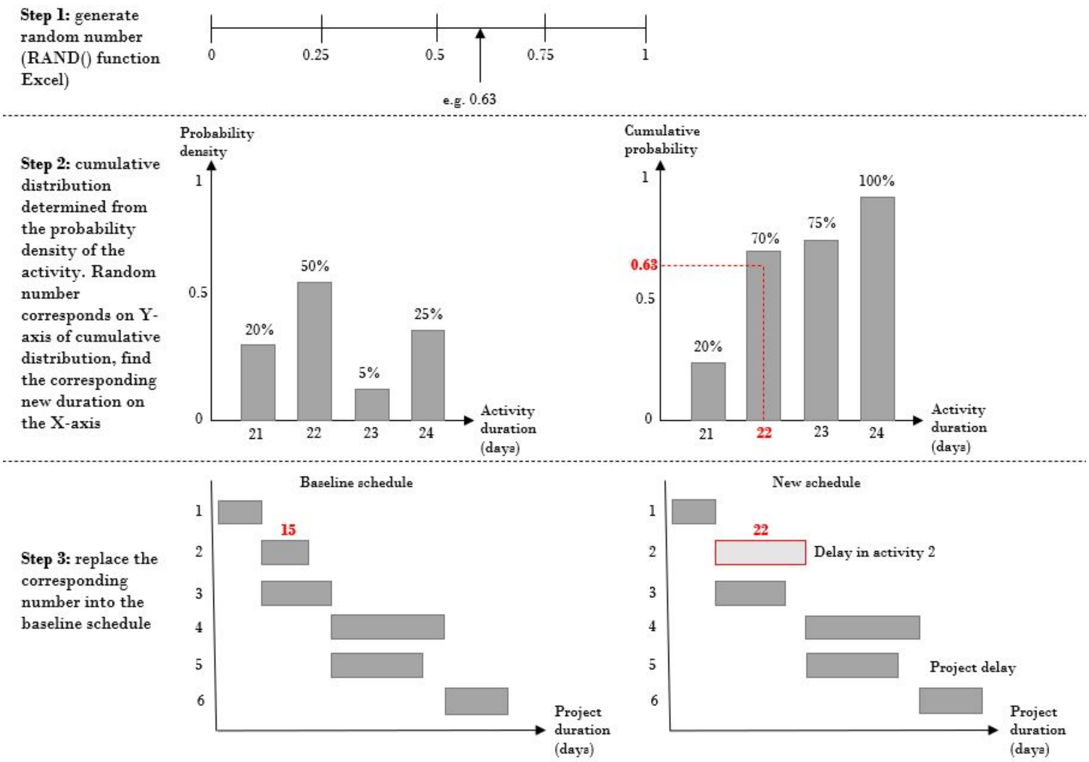


Figure 2.5: Three steps for executing the Monte-Carlo simulation

According to Technopedia (2017), a random number generator is a mathematical construct that generates a random set of numbers that have no discernible pattern in the generation. For the Monte-Carlo simulation, a random number generator is used to determine for each iteration a new number. Every activity has its own beta distribution with a corresponding cumulative distribution. According to Aurora (2012), *"the cumulative distribution function $F_x(x)$ describes the probability that a random variable x with a given probability distribution will be found at a value less than or equal to x"*. The cumulative distribution is displayed in Formula 2.14.

$$F_x(x) = \mathbb{P}(X \leq x) = \int_{-\infty}^{x} f_x(u)du \tag{2.14}$$

When the random number (a number between 0 and 1) is generated, this will correspond to a percentage of the cumulative distribution of the activity. With the corresponding percentage, the duration of the activity is determined (see step 2 of Figure 2.5). The corresponding duration of the cumulative distribution will be used in the schedule as the new duration of that particular activity. It is possible to see if this new schedule deviates from the baseline schedule.

2.5 Simulation output

During the simulation, all project schedules and critical paths are recorded. Several indices can be used to interpret the simulation output (Vanhoucke, 2013). The criticality index (CI), the significance index (SI) and the schedule sensitivity index (SSI) are these measurements. These indices give the critical path a degree of sensitivity to determine if an activity is critical or not and if action needs to be undertaken to decrease the impact/occurrence of the risks.

2.5.1 Criticality index

Each node (activity) has a criticality index (De Marco, 2011). This index states whether or not an activity is on the critical path. This can be helpful when optimising the schedule. An activity with a high criticality index value has to be monitored closely to ensure that the project does not develop a delay (falls behind schedule). The Monte-Carlo simulation obtains the index and expresses a percentage of the likelihood of an activity being critical (Vanhoucke, 2013). The criticality index is based on the simulation, this is denoted as $\widehat{CI}$. This is calculated as the frequency of an activity being critical over several simulations, $k = 1, ..., n$. The formula for these simulations is given in Formula 2.15, where tf is the total float. As mentioned in Section 2.2.2, when the total float is 0, the activity is critical.

$$\widehat{CI} = \frac{1}{n} \sum_{k=1}^{n} 1(tf_i^k = 0) \tag{2.15}$$

$$\mathbf{1}(tf_i^k = 0) = \begin{cases} 1 & \text{if } tf_i^k = 0 \text{ is true} \\ 0 & \text{if } tf_i^k = 0 \text{ is false} \end{cases} \tag{2.16}$$

2.5.2 Significance index

The significance index reflects the importance of activities over the total duration of the project (Vanhoucke, 2013). To measure the importance between the activities the general formula is given in Formula 2.17, where RD is the simulated project duration, and the formula to measure the significance index is given in Formula 2.18.

$$SI = \mathbb{E}\left(\frac{d_i}{d_i + tf_i} * \frac{RD}{\mathbb{E}(RD)} \right) \tag{2.17}$$

$$\widehat{SI} = \frac{1}{n} \sum_{k=1}^{n} \left(\frac{d_i^k}{d_i^k + tf_i^k} \right) \left(\frac{RD^k}{\frac{1}{n} \sum_{k=1}^{n} RD^k} \right) \tag{2.18}$$

When the significance indices of the activities are known, a distinction can be made between the sensitive and insensitive activities. It is vital to keep a close eye to the sensitive activities because they have the highest chance to delay the project.

2.5.3 Schedule sensitivity index

According to Project Management Institute (2013), there are many ways to do a risk assessment. Quantitative analysis is one of them. In this book the activity duration and project duration's standard deviation (σ_{d_i} and σ_{RD}) are combined with the criticality index. The general formula is given in Formula 2.19 and when the schedule sensitivity index is used in simulations, Formula 2.20 is used.

$$SSI = \sqrt{\frac{var(d_i)}{var(RD)}} * CI \tag{2.19}$$

$$\widehat{SSI} = \frac{\sigma_{d_i} * \widehat{CI}}{\sigma_{RD}} \tag{2.20}$$

2.6 Conclusion

In this chapter, the research question *which methods can be used to create a risk analysis* and its sub-questions are answered. These subquestions are:

- What is a baseline schedule?
- What methods can be used to schedule activities?
- How can risks be defined?
- What method can be used to create a simulation model?
- How are the simulation outputs measured?

First, the baseline schedule was explained in Section 2.1. Baseline scheduling can prevent delays and is the basis/first timeline a project team makes. The performance indicators can be monitored to detect deviations from the baseline. This helps to identify the delays that can occur.

The methods to schedule activities are discussed in Section 2.2, there are two methods: CPM and PERT. CPM is used to determine how long activities in the project can be postponed without delaying the project, PERT is used when durations are uncertain and estimates the probability that the project finishes by the given deadline. How risks are defined is explained in Section 2.3, risks can have a rating to determine how much influence they have on activities. The risk rating formula is Risk rating = likelihood of occurrence $*$ severity of the risk, so risk ratings are dependent on the likelihood of occurrence and the severity of the risk on the activity. In this research a simulation is used, the Monte-Carlo simulation is explained in Section 2.4 and interpreting the simulation outputs (critical index, significance index and schedule sensitivity index) is explained in Section 2.5.

Chapter 3

Current situation

This chapter explains the current situation of Project X, which answers one research questions and five sub-question:

- What is the current schedule of Project X?
  - What activities need to be scheduled?
  - What are the milestones of the project?
  - What is the project's network?
- What are the risks of the project?

First, the current schedule is identified (Section 3.1) with its activities, milestones and network. Secondly, the occurring risks in the project are mentioned (Section 3.2). Thirdly, a survey is distributed to identify the parameters of the risks (Section 3.3).

3.1 Schedule

Scheduling is the most important part when making a risk analysis. The risk analysis can only be executed when there is a schedule. Activities should be selected, identified, analysed and arranged to determine the schedule. Microsoft Excel is used to create a schedule (Gantt chart), a timeline and to identify the critical path.

All the activities of the project are examined and identified to make the schedule. The activities are defined by discussing the project and the dates of the activities with their relationships to each other with G. van Essen. After the discussions, the Gantt chart and table has been made, which will be used for the survey. The duration of the activities are dependent on the working days of the employees and their vacation days (*due to confidential issues, the table is removed.*). The working days are from Monday up to and including Friday, each working days consists of 8 hours. The starting date of the project is 01-01-2020, and the intended finish date of the project is 01-09-2021.

3.1.1 Activities

All the activities are illustrated in Table 3.2. Below, all the activities will be explained with their relationships. In total, there are seven main phases/activities, seven sub-activities of two main phases and four of these sub-phases consist of three other phases.

Due to confidential issues, the descriptions of the activities are removed.

Each activity has a relationship with another activity which has to be included in the schedules of the project. Section 2.2.1 discussed the different relationships that can occur. These relationships are necessary to make the schedule and see whether or not the activities influence each other. Due to a conversation with the leading stakeholder, the relationships are identified. The relationships are depicted in Table 3.1, it explains the relationship between activity i and j. These relationships are abbreviations, where (just as stated in Section 2.2.1) FS means finish-to-start, SS means start-to-start and FF means finish-to-finish.

The activities with their finish and starting dates are depicted in Table 3.2. The relationships between the different activities are included in the dates (start and finish) of the activities. For each activity, the total duration (in working days) is given in the last column.

As the table shows, the end date of phase B.1.3 is already finished according to the planned duration of the project team. But currently the phase is still not done and has a delay where the duration of the delay is not known yet. The dates of the activities and the relationships between the activities are depicted in a Gantt chart which is depicted in Figure 3.1.

Table 3.1: Relationship between activity i and j

i	j	Relationship	Time lag
A	B.1.1	FS	-
B.1.1	B.1.2	FS	-
B.1.2	B.1.3	FS	-
B.1.3	B.2.1	SS	-
B.2.1	B.2.2	FS	-
B.2.2	B.2.3	FS	-
B.2.3	B.3.1	SS	-
B.3.1	B.3.2	FS	-
B.3.2	B.3.3	FS	-
G.4	C	FF	-
G.4	D	FF	-
B.3.1	E	FS	-
B.1.3	F	SS	21 days
B.1.3	G.1	SS	21 days
B.3.3	G.2	FS	-
B.3.3	G.3.1	FS	-
G.3.1	G.3.2	FS	-
G.3.1	G.3.3	FS	-
G.3.3	G.4	FS	-

Figure 3.1: The schedule of the activities with their duration, start date and end date

Table 3.2: Activities

Phase	**Start date**	**End date**	**Working days**
A	02-01-2020	28-02-2020	40
B			
B.1			
B.1.1	03-03-2020	30-04-2020	38
B.1.2	04-05-2020	29-05-2020	19
B.1.3	01-06-2020	31-08-2020	64
B.2			
B.2.1	01-06-2020	31-07-2020	44
B.2.2	04-08-2020	31-08-2020	20
B.2.3	01-09-2020	30-10-2020	44
B.3			
B.3.1	01-09-2020	30-10-2020	44
B.3.2	02-11-2020	30-11-2020	21
B.3.3	01-12-2020	29-01-2021	34
C	02-01-2020	30-07-2021	390
D	02-01-2020	30-07-2021	390
E	02-11-2020	30-07-2021	185
F	01-07-2020	30-07-2021	272
G			
G.1	01-07-2020	30-07-2021	272
G.2	01-02-2021	30-07-2021	130
G.3			
G.3.1	01-02-2021	26-02-2021	20
G.3.2	01-03-2021	30-04-2021	45
G.3.3	01-03-2021	30-07-2021	110
G.4	02-08-2021	31-08-2021	22

In this research the pessimistic time estimation, optimistic time estimation and realistic time estimation, according to the PERT method discussed in Section 2.2.3, are determined with the help of a survey sent to the stakeholders. They estimated the time estimations of the activities. This is a new innovative project, so no data is known about this project yet. Therefore, the survey to the stakeholders was important to get more insights of the project. Without this survey, this research was not reachable. The results of the survey are explained in Section 3.3.

3.1.2 Network

When a critical path is necessary to identify, a network must be made. This network is based on Section 2.2. For this project, the AON network and its critical path are determined, depicted in Figure 3.2, where the red path is the critical path and the duration of the activities are included within the brackets below the activities. The values are based on Table 3.2.

There are ten different paths in total, where path five is the critical path (based on the original schedule of Table 3.2). The duration of the path is 412 working days. All the other paths, with the exception of path one, two and four, have a duration of 390 working days. These paths all finish at the same time. Path one has a duration of 161 working days, path two has a duration of 205 working days and path four has a duration of 325 working days.

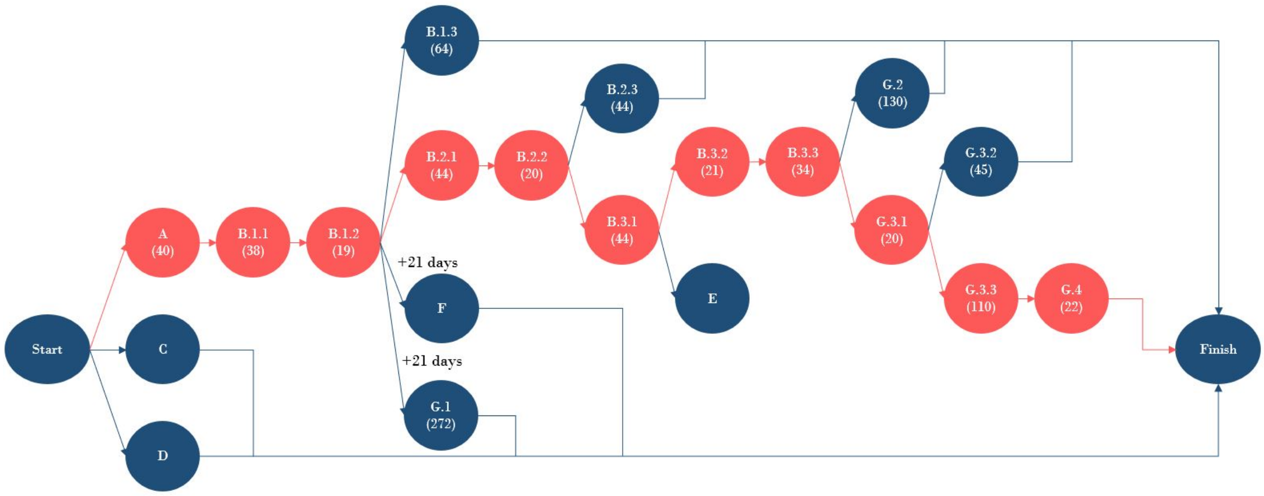


Figure 3.2: AON network

1. Start - A - B.1.1 - B.1.2 - B.1.3 - Finish
2. Start - A - B.1.1 - B.1.2 - B.2.1 - B.2.2 - B.2.3 - Finish
3. Start - A - B.1.1 - B.1.2 - B.2.1 - B.2.2 - B.3.1 - B.3.2 - B.3.3 - G.2 - Finish
4. Start - A - B.1.1 - B.1.2 - B.2.1 - B.2.2 - B.3.1 - B.3.2 - B.3.3 - G.3.1 - G.3.2 - Finish
5. Start - A - B.1.1 - B.1.2 - B.2.1 - B.2.2 - B.3.1 - B.3.2 - B.3.3 - G.3.1 - G.3.3 - G.4 - Finish
6. Start - A - B.1.1 - B.1.2 - B.2.1 - B.2.2 - B.3.1 - E - Finish
7. Start - A - B.1.1 - B.1.2 - F - Finish
8. Start - A - B.1.1 - B.1.2 - G.1 - Finish
9. Start - C - Finish
10. Start - D - Finish

3.1.3 Milestones

In the project, several milestones are involved. One of these milestones is the election of a new mayor, which is happening on the first of November. For this milestone, the tangible results of phase B.1 and phase B.2 must be present. When there is a new mayor, the mayor can decide to stop the project. To decrease the chance of cancelling the project, physical evidence of the project must be available. The visible evidence is at the end of phase B.2. For the current mayor, it is essential to have these results before the elections to get more votes. When she is re-elected, the project can continue as planned. When she is not re-elected, the project team need to have tangible results of phase B.1 and phase B.2 to convince the next mayor that the project is important and should continue.

The second milestone is the World Water Day, happening on the twenty-second of March. For this milestone, phase B.3.3 must be finished.

The third milestone is the delivery date of the project. The project must be finished on the thirty-first of August in 2021. All milestones are added to the timeline of Figure 3.3.

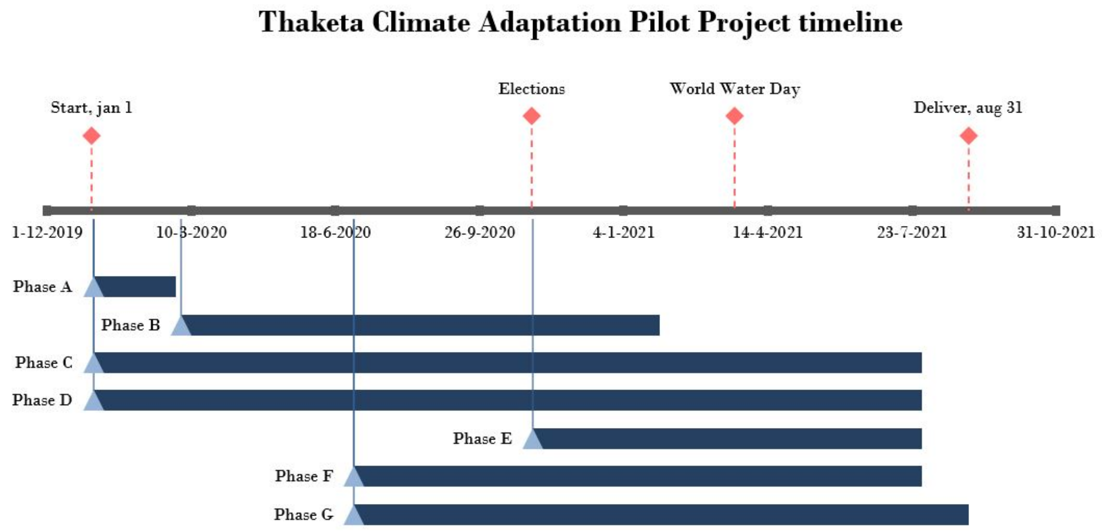


Figure 3.3: Timeline with its milestones

3.2 Risks

Each consequence of the risks can have a significant or minor impact on the duration of the project. The impact of the risks on the project is defined with the help of a survey. The survey is displayed in Appendix B. From this survey, the risks of each activity are determined, these are placed in a risk matrix. The results of the survey are briefly discussed in Section 3.3.2, the distributions of the activities, based on the results of the survey, are discussed in 5.1. There are various categories of risk, as mentioned in Section 2.3. These categories are a financial and economic risk, operational risk, safety and social risk, design risk and force majeure risk. There are some name changes to clarify the categories better and make it a bit broader. Design risks become intervention risks, and force majeure risks are external risks.

Due to confidential issues, this part of this section is removed.

For each category, different risks are identified with the help of the main stakeholder. When stakeholders identified other risks that involve an activity, they could add it to the survey, so all major risks are included in this research.

Due to confidential issues, the list of the risks is removed.

3.3 Survey

When reporting a survey, there are specific steps that need to be taken. The next paragraph is based on the steps of Kelly et al. (2003). The purpose of the research is to collect information about the different risks that influence the activities of the schedule. The results of the survey will contribute to answering the core problem of this research: *What risks should be prevented to finish Project X in time?*.

With the results of the survey, a risk matrix is made, as described in Section 2.3. Also, it is possible to see the most urgent risks in an overview, and the parameters (*min, mode, max*), explained in Section 2.2.3, of the activities can be identified. These results are necessary for making the Monte-Carlo simulation, as the simulation will simulate the schedule, taking into account the distributions of the activities, which are based on the PERT parameters.

A survey is chosen to conduct the information necessary for the simulation model. A survey is a quantitative method which helps to identify the necessary information. It is an excellent method because it is easier to administer the data, inexpensive, and it can be administered online. The online method is convenient in the COVID-19 period and more accessible when stakeholders are located in other countries as is the case of this project. Moreover, the program Qualtrics can transform the answers of the respondent to an Excile file; people can fill out the survey when they have time and when they want to do it; furthermore, a survey is less time consuming than an interview.

A disadvantage of the survey is the size of the research population. For surveys, it is essential to have a large number of respondents; for this survey, only stakeholders of the pilot project are asked to fill out the survey. Unfortunately, the group of respondents is relatively small, but because of the knowledge of the stakeholders/experts about the project, the surveys they answered can be trusted as reliable. They have all the knowledge about the project, and therefore their answers to the survey are necessary and trustworthy. Stakeholders could be biased when they filled out this survey, which can make the estimations more optimistic or pessimistic than the reality. These biased answers could not be filtered out since it is not possible to know how optimistic or pessimistic they answered the survey. So this research is dependent on the answers of the respondents. The respondents are contacted by email, including an explanation about this Bachelor thesis and why their answers are crucial. The determination of the parameters are necessary to include in the survey, as this is a new innovative project, which means that there is no data known about the parameters of activities of the project.

In the survey, the respondents were asked to give their opinions and expertise. The results were simulated to see the best-estimated duration of the activities to make this thesis more quantitative. With these results, the stakeholders know which interventions need extra attention.

3.3.1 Questions

In this section, the questions of the survey are discussed. A part of the survey is added to Appendix B. The consent statement is added plus the first three questions of the survey. The other phases consist of the same questions as the first phase. Only the questions of phase C, phase D, phase E, phase F and phase G.4 are different as they continue through the whole project or stop when the project is finished, and phase G.4 has a fixed duration of one month, as stated before in Section 3.1.1. As a result, their parameters are not necessary to ask because this will not influence the activities. As such, only the risks are asked to know if the stakeholders should keep attention to specific activities.

The survey starts with the consent statement the participants need to accept. Here is stated that the survey is not anonymous (because motivations can be asked later), furthermore the motivation of the thesis is explained and the data collection method. When the participants accept the consent form, it is officially possible to use the data of the survey for this thesis.

In the next tab, the participants can find the high-level project planning (Figure 3.1). The four questions are mentioned at the beginning to inform the participants, and some notes are named.

1. There are no questions about phase A, phase B.1.1 and phase B.1.2 because these phases are already finished.

2. Phases C, D E and F do not contain questions about their duration as they finish when the project is completed, so the duration of the activities depends on the duration of the project. When the project finishes earlier, these phases also finish earlier, when the project finishes later, these phases also finish later.

3. Phase G.4 has a fixed duration, therefore the questions about the optimistic, realistic and pessimistic duration of the activity are not mentioned in the survey.

4. It is possible to leave the survey and re-enter it later where you left off (please use the same link again). After the participant exits the survey, they have five days to return to the survey and finish it.

These notes will clarify some questions for the participants, and they can re-enter the survey later if they want.

For each activity, the participants have to identify the top three risks and the severity (level) of the risks. The severity can have a value of one, two, three, four or five (see Figure 2.3 in Section 2.3). A value of one suggests that the risk is negligible, two that the risk is low, three moderate, four significant and five severe (catastrophic). Next, the participants need to identify the impact of the risks by determining the most pessimistic time estimation (delay) of the duration of an activity. The most optimistic time estimation (the shortest time a phase could take) and a realistic time estimation of the duration of the activity are also asked, as the parameters are necessary to know for the simulation model (*min, mode and max*). They are determining the scenarios by sliding the bar to a particular month. In the beginning, the bar indicates the planned duration stated in Section 3.1. The number of weeks per activity is also mentioned to clarify the duration to the participants.

3.3.2 Results

With the help of the survey, the *min* (optimistic), *max* (pessimistic) and *mode* (realistic) values of the activities are determined. The realistic time estimation is the value which is most assigned by the participants for the activity. The pessimistic duration is when all risks occur, so the worst-case scenario of the duration of the activity. The optimistic duration is when no risks occur, so the best-case scenario of the duration of the activity. The participants were asked to determine the date of the three time estimations. From these dates, the duration in working days was determined with the help of Excel.

A simulation model was made and explained in Chapter 4 to determine the most likely time estimation for the project. Each stakeholder determined the values; from these values, the distribution of the activity was determined. These distributions are depicted in Section 5.1. The parameters of the activities and its function are depicted in Table 5.1.

The expected time of an activity can be determined with the help of Formula 2.7 in Section 2.2.3. The responses of the participants are summarised in Appendix C.

This was a long and hard survey according to the participants, but useful for the project. 18 stakeholders were asked to fill out the survey. 13 out of 18 stakeholders responded and filled out the survey, as almost every participant works for a different company, there is no bias relative to the different companies and their perspectives. The length of the survey can influences the results of the participants negatively, sometimes without their knowledge because it takes too long. The values of the surveys are used for the simulation to simulate the most likely duration of the activities. According to the surveys filled out by the stakeholders, some activities contain other risks than the given risks of the survey. These risks and concerning activities are:

Due to confidential issues, the list of the additional risks is removed.

Often, the other risks were mentioned without indicating the rating and severity of the risks. Therefore, these risks are not included in the analysis. Overall the survey made a lot clear about how the participants think about the project. Some are very optimistic about the project and think everything will be finished in time, where others have a very pessimistic view and think the project will be delayed a lot.

3.4 Conclusion

In this chapter, two research questions are answered:

- What is the current schedule of Project X?
  - What activities need to be scheduled?
  - What are the milestones of the project?
  - What is the project's network?
- What are the risks of the project?

The schedule is discussed in Section 3.1, where all the activities and its milestones are explained. It is supported by a figure of the schedule (Figure 3.1), and the milestones are depicted in Figure 3.3. The critical path is: Start - A - B.1.1 - B.1.2 - B.2.1 - B.2.2 - B.3.1 - B.3.2 - B.3.3 - C.2.1 - C.2.3 - C.3, depicted in Figure 3.2

In Section 3.2, all the risks have been identified that influence the project. Additionally, in Section 3.3.2, more risks are identified by the stakeholders.

Chapter 4

Simulation model

In this chapter, the simulation model made for this research is explained. First, the general simulation is explained in Section 4.1. Then the scenario analysis is explained in Section 4.2. For the scenarios a Monte-Carlo simulation will determine if the scenarios are reducing the duration of the whole project.

4.1 Model

A model in Microsoft Excel was created to perform a simulation. For each simulation, 1000 iterations are needed to ensure the reliability of the model (Barreras, 2011). When fewer iterations are performed the error becomes bigger, these 1000 iterations ensure that the error is smaller. This means that when the error is lower, the simulation is more reliable as the deviation is less (Driels & Shin, 2004). This is based on the formula $n = (\frac{z_{\alpha/2} * \sigma}{E})^2$, where E is the error and σ is the standard deviation of the whole project, so the critical path of the project in the baseline. The estimates (min and max) are based on the responses of the participants of the survey. For this formula it is assumed that the project follows a normal distribution. The error should not be more than ten working days, as this will influence the project by more than two weeks, which causes a too long delay of the project. The error should be bigger than five working days as this will only be influencing the project a week, which is fine for the stakeholders. This means that the error should lay around seven working days. With this in mind the total amount of iterations should be 938.98, but when it is rounded up, the error is a bit smaller so we can say for sure that 1000 iterations is reliable. The accuracy of the simulation will lay within seven working days 95% of the time. The criticality index of each activity (Formula 2.15) is calculated using this simulation model. Moreover, the average duration of each activity is calculated with Formula 4.1, where RD is the simulated duration of an activity, and n is the total number of iterations.

$$\text{Average duration} = \frac{1}{n}\sum_{k=1}^{n} RD_k \tag{4.1}$$

In this model, the average duration of the project can be compared with the planned duration of the project. The total duration of the project was determined with the simulated duration of each activity. The total duration of the project per iteration is based on the critical path.

Each activity has its own optimistic, pessimistic and realistic duration. These durations were determined with the survey explained in Section 3.3. Each activity has its distribution (Section 5.1) which is dependent on α and β and the three estimations that were determined with the survey. The probability density function of the activity is based on Formula 2.6.

For every x, the duration of the activity, a corresponding $f(x)$ can be found. A basic Excel function corresponds to Formula 2.6, therefore this function is used in the simulation model.

As is possible to see in the function, the alpha, beta, optimistic time estimation, and pessimistic time estimation must be known. Alpha and beta were determined with Formula 2.4 and Formula 2.5 and as previously mentioned, the optimistic and pessimistic time estimations were determined with the help of the survey. Where the optimistic time estimation is the minimum value mentioned by the participants, and the pessimistic time estimation is the maximum value mentioned. The cumulative distribution helps to determine the new duration of an activity. The random number generator generates a number from 0 up to and including 1, which corresponds to a value of the cumulative distribution.

In the simulation, a random number was generated, which corresponds to the cumulative distribution. The corresponding duration x was placed in two different sheets. One of these sheets is a sheet about the simulated duration of the activities per iteration. The other one is a sheet where the critical path is determined.

For each iteration, a random number was appointed to an activity. This random number determines the duration of the activity, as stated above. Activities A, B.1.1 and B.1.2 keep their planned duration (Table 3.2) since they are already finished. Their planned duration is the actual duration of the activities. Activities C, D, E, F and G.4 are also not included as G.4 has a fixed duration of 22 working days and the other four phases are dependent on the total duration of the project. For other activities, the new duration is added per iteration. So it is possible to see all the durations of the activities per iteration. Also, the total duration per iteration is calculated. This total duration is determined with the help of the critical path. This process is depicted in Figure 4.1. In this figure first the random number is chosen, next the corresponding duration according to the cumulative distribution is determined and this duration of a certain activity is placed in the schedule. This happens for each activity in each iteration.

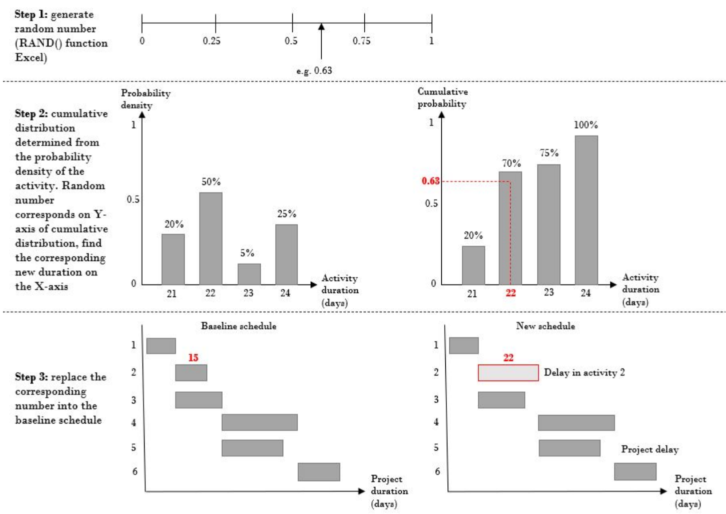


Figure 4.1: The steps to generate the new duration of the activities in the simulation model

Since each activity has a new randomly generated duration per iteration, the critical path will change per iteration. As mentioned in Section 3.1.2, there are ten paths in total. Each path is added to the simulation model by by applying a zero or one to the activities. When the activity has the value of zero, this activity lays not on the path, when it has a value of one, the path contains this activity, see Figure 4.2. Then the total duration per path is calculated, the critical path gets the color red and is added to a new sheet where all the critical paths of the simulations are saved. With these numbers, the critical index

(CI, Formula 2.16) of an activity can be calculated, and it is possible to see whether or not changing the duration of an activity can have a big influence on the total project duration or not. In Figure 4.2 paths 6, 7, 9 and 10 do not contain an total duration in this figure as the activities that are part of these paths adjust themselves to the most critical project duration as stated in Section 3.1.1. So activities C, D, E and F are adjusting their end dates to the end date of the project. A cause of these adjustments is that these activities can never lay in the critical path because they can be abridged and extended. Therefore their duration in the simulation model is fixed so they do not influence the determination of the critical path. To make sure that they are never ending in the critical path, their end durations are deleted in the model.

Activities																					
	A	B.1.1	B.1.2	B.1.3	B.2.1	B.2.2	B.2.3	B.3.1	B.3.2	B.3.3	C	D	E	F	G.1	G.2	G.3.1	G.3.2	G.3.3	G.4	
Duration																					
days:	40	38	19	52	88	41	83	49	30	65	390	390	185	272	234	130	14	51	100	22	
Paths																					Duration
Path 1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	149
Path 2	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	309
Path 3	1	1	1	0	1	1	0	1	1	1	0	0	0	0	0	1	0	0	0	0	500
Path 4	1	1	1	0	1	1	0	1	1	1	0	0	0	0	0	0	1	1	0	0	435
Path 5	1	1	1	0	1	1	0	1	1	1	0	0	0	0	0	0	1	0	1	1	506
Path 6	1	1	1	0	1	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	
Path 7	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	
Path 8	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	440
Path 9	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	
Path 10	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	

Figure 4.2: Critical path per activity with its new duration

4.2 Scenario analysis

For the scenario analysis, the same simulation model is used as for the first simulation. This scenario analysis is necessary to see if preventing risks in different situations can influence the duration of the project. In the scenario analysis, different scenarios are simulated. Due to these simulations, it is possible to see whether or not a different scenario has a significant influence on the total duration of a project.

In total five scenarios will be investigated. The first simulation, with the estimations of the participants of the survey will result in an optimistic, pessimistic and most realistic time estimation of the total duration of the project. So the first three scenarios will be about these three estimations. When these three estimates are investigated, it is possible to see when the risks are prevented based on the activities that are part of the critical path, if the total duration of the estimations will decrease. One other scenario is based on the critical index of the first simulation. Also, the variance and standard deviation of each activity have to be determined. Risks of the activities with the highest CI value will be prevented. When these risks are prevented, it is possible to see whether or not preventing risks will help to decrease the duration of the project. The last scenario will be about the most occurring risks. With the help of the survey, the risks of the project and each activity are determined. Based on the most occurring and the highest severity, risks will be prevented for all activities.

Whether or not a scenario influences the project can be determined by analysing the sensitivity, standard deviation and variance. When these values are reduced, the scenario has a positive influence on the duration of the project. If the project duration is not reduced, the scenario has a adverse influence on the project. The trade-off between the investment of the scenario and the influence of the duration has to be determined.

4.3 Conclusion

With the simulation model, it is possible to see which risks influence activities. When an activity has an average duration which is higher than the realistic time estimation, the activity will take longer than it should be. The delay in the activities is due to the risks involved in the activity. When the activity is also laying in the critical path, the project team needs to keep a close eye to this activity. The risks that influence the activity which is on the critical path and has a delay will delay the whole project.

The scenario analysis will determine if solutions will influence the project. Moreover, different scenarios will be created. Due to this analysis, it is possible to see how much the risks influence the project by comparing the new duration and outcome of the simulation with the first/old simulation model.

Chapter 5

Results

In this chapter, two research questions and two sub-questions are answered:

- What risks influence the duration of the project?
  - What is the impact of the involved risks?
- What solutions can be created to prevent the risks of Project X?
  - What solutions are there to prevent the risks of an activity?
  - How much do these solutions influence the end date of the project?

First, the activities are explained with risks per activity (Section 5.1.2) and the distribution of the activities (Section 5.1.1). Then the results of the Monte-Carlo simulation are discussed (Section 5.2) and several scenarios are analysed (Section 5.3).

5.1 Activities

In Section 3.1.1, the activities of the project were identified. Each activity is mentioned in the survey, and the participants answered the questions (Appendix B). Every activity has risks that can influence the activity. For each phase, the risks are identified and placed in a risk matrix. These identified risks are discussed in Section 5.1.2, where it is possible to see if certain risks have more influence on the activity than other risks.

Additionally, the participants of the survey were asked about the duration of the activities, what is the realistic, optimistic and pessimistic time estimation of each activity. Only the duration of phase C, D, E, F and G.4 cannot be affected by the risks since phases C, D, E and F are already started and finish one month before the end date of the project, even when the project is delayed. Phase G.4 has a planned duration of one month, 22 working days (Table 3.2). This is based on the planned duration of the month of August since that activity can start on 02-08-2021 and is finished on 31-08-2021. When these days were calculated, the holidays and weekends were taken into account and are kept out of the 22 working days. This phase cannot be delayed, and the duration is fixed since this phase only contains reporting and risks do not influence this duration. These estimations were processed in an Excel file and discussed in Section 5.1.1. The results of the distributions were used to perform a Monte-Carlo analysis, where the basis is mentioned in Section 4.1, and the results of the simulation are discussed in Section 5.2. Phase A, phase B.1.1 and phase B.1.2 are not added with their risks and time estimations since they are already finished, in the simulation model they are added with their planned duration.

5.1.1 Distributions

Each activity has a distribution which is based on Formula 2.6. The parameters for creating the PDF are calculated and shown in Table 5.1, these formulas are based on Formula 2.4 and Formula 2.5. The parameter *min* is the shortest time an activity can take; this value is determined by finding the minimum value of all respondents of the survey. The longest time of an activity, *max*, is determined by finding the maximum value of days an activity can take according to the participants of the survey. The *mode* value is the mode, the number of days that occurs the most in the participants answers, of the distribution. The distribution of each activity is depicted in Appendix D Figures 21-32, with the PDF on the first y-axis and its corresponding CDF on the second y-axis. How the distribution is skewed is also mentioned in these figures. As mentioned before, phases C, D, E, F and G.4 are not included since their durations are fixed or adjust to the end date.

Table 5.1: The parameters of every activity according to the survey

Phase	**min**	**mode**	**max**	$\boldsymbol{\alpha}$	$\boldsymbol{\beta}$	$\boldsymbol{f(x)=}$
B.1.3	21	64	183	2.95	5.63	$\frac{\Gamma(8.58)}{\Gamma(2.95)\Gamma(5.63)} * \frac{(x-21)^{1.95}(183-x)^{4.63}}{(162)^{7.58}}$
B.2.1	21	64	129	4.16	5.46	$\frac{\Gamma(9.62)}{\Gamma(4.16)\Gamma(5.46)} * \frac{(x-21)^{3.16}(129-x)^{4.46}}{(108)^{8.62}}$
B.2.2	20	20	85	1.45	7.23	$\frac{\Gamma(8.68)}{\Gamma(1.45)\Gamma(7.23)} * \frac{(x-20)^{0.45}(85-x)^{6.23}}{(65)^{7.68}}$
B.2.3	22	79	119	5.20	4.11	$\frac{\Gamma(9.31)}{\Gamma(5.20)\Gamma(4.11)} * \frac{(x-22)^{4.20}(119-x)^{3.11}}{(97)^{8.31}}$
B.3.1	22	44	119	3.02	6.47	$\frac{\Gamma(9.49)}{\Gamma(3.02)\Gamma(6.47)} * \frac{(x-22)^{2.02}(119-x)^{5.47}}{(97)^{8.49}}$
B.3.2	21	21	75	1.65	8.27	$\frac{\Gamma(9.92)}{\Gamma(1.65)\Gamma(8.27)} * \frac{(x-a)^{0.65}(b-x)^{7.27}}{(54)^{8.92}}$
B.3.3	14	54	120	3.76	5.23	$\frac{\Gamma(8.99)}{\Gamma(3.76)\Gamma(5.23)} * \frac{(x-14)^{2.76}(120-x)^{4.23}}{(106)^{7.99}}$
G.1	185	272	337	8.89	7.32	$\frac{\Gamma(16.21)}{\Gamma(8.89)\Gamma(7.32)} * \frac{(x-185)^{7.89}(337-x)^{6.32}}{(152)^{15.21}}$
G.2	65	130	195	5.97	5.97	$\frac{\Gamma(11.94)}{\Gamma(5.97)\Gamma(5.97)} * \frac{(x-65)^{4.97}(195-x)^{4.97}}{(130)^{10.94}}$
G.3.1	10	20	108	1.59	5.19	$\frac{\Gamma(6.78)}{\Gamma(1.59)\Gamma(5.19)} * \frac{(x-10)^{0.59}(108-x)^{4.19}}{98)^{5.78}}$
G.3.2	11	45	131	2.92	5.29	$\frac{\Gamma(8.31)}{\Gamma(2.92)\Gamma(5.29)} * \frac{(x-11)^{1.92}(131-x)^{4.29}}{(120)^{7.31}}$
G.3.3	65	110	197	5.00	7.70	$\frac{\Gamma(12.70)}{\Gamma(5.00)\Gamma(7.70)} * \frac{(x-65)^{\alpha-1}(110-x)^{\beta-1}}{(45)^{11.70}}$

5.1.2 Risks

Each activity has risks that can influence the duration of the project. In Figure 5.2 activities with their risks are attached; these values are joined into a risk matrix. In this matrix, it is possible to see if the risk has a major impact on the duration of the activity (red zone) or if the impact is less (orange and green zone). As shown in Figure 2.3, the y-axis represents the severity of the risk, and the x-axis represents the corresponding likelihood. The respondents have rated their top three risks per activity, and the severity level of the risks. With these two values, the likelihood can be calculated as:

$$likelihood\,of\;occurrence = \frac{risk\;rating}{severity\;of\;the\;risk}$$

Since the respondents determined the level of the risks and its severity, these values are summed up. The ratings are transformed as the most important risks have the highest level. To each rating, a score was attached. When the risk was first rated by the respondents, the score of the calculation was a three. For the second-rated risk, the score was a two, and for the third-rated risk, the score was a one. When the ratings are attached to the risks, the level of the important risks becomes more crucial. Each risk can be identified in a zone, red, orange or green. If the risk occurs in a red zone, the project manager needs to keep a close eye to this risk since these risks can influence the project duration significantly. Letters are used to simplify the figures. Each letter represents a risk. The risks and the corresponding letters are depicted in Table 5.2 on page 33.

Table 5.2: Legend of the risks

	Risk		Risks
a	*Confidential*	v	*Confidential*
b	*Confidential*	w	*Confidential*
c	*Confidential*	x	*Confidential*
d	*Confidential*	y	*Confidential*
e	*Confidential*	z	*Confidential*
f	*Confidential*	aa	*Confidential*
g	*Confidential*	ab	*Confidential*
h	*Confidential*	ac	*Confidential*
i	*Confidential*	ad	*Confidential*
j	*Confidential*	ae	*Confidential*
k	*Confidential*	af	*Confidential*
l	*Confidential*	ag	*Confidential*
m	*Confidential*	ah	*Confidential*
n	*Confidential*	ai	*Confidential*
o	*Confidential*	aj	*Confidential*
p	*Confidential*	ak	*Confidential*
q	*Confidential*	al	*Confidential*
r	*Confidential*	am	*Confidential*
s	*Confidential*	an	*Confidential*
t	*Confidential*	ao	*Confidential*
u	*Confidential*		

In Figure 5.1 all the risks of all the activities are summarised. It is possible to see the most important risks, and the impact of the risks when they occur. As the figure shows, risk *v* has the most impact of all risks. Risks *ac*, *s*, *f*, *a* and *g* are also occurring in the red/orange zone. Risks *f*, *g*, and *s* occur 13 times as risks of activities, where risks *ac*, occurs 12 times. Risk *a* occurs 11 times and risks *v* occurs 9 times. As risk *v* occurs less times than the other risks and the severity level of this risk is the highest, the impact of this risk on the activities where it occurs is very significant. These calculations are based on the risks of the different activities. Each value is added and this can be seen in Figure 5.1. For example, when risk *xy* has a severity of 2 in phase B.3.1 and a severity of 4 in phase B.3.3, the total severity in the figure becomes 6. The same applies to the likelihood of the risks.

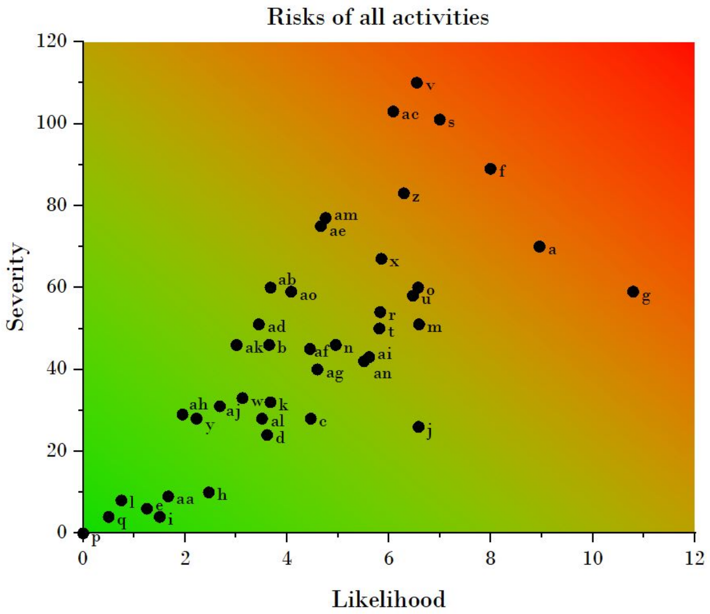
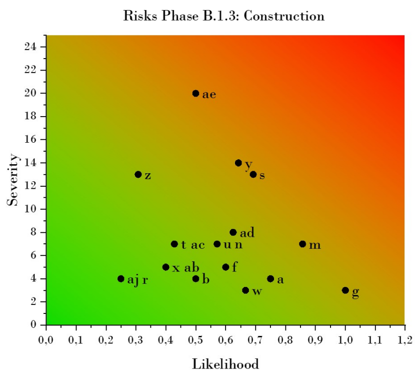
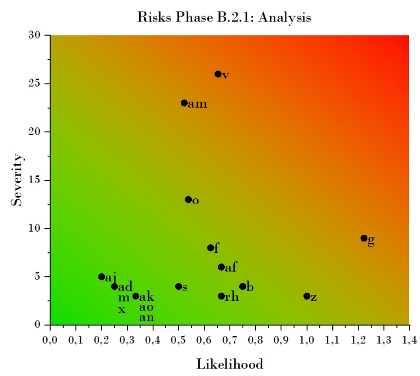


Figure 5.1: Risks v, ac, s, f, a and g are the most crucial risks for all the activities

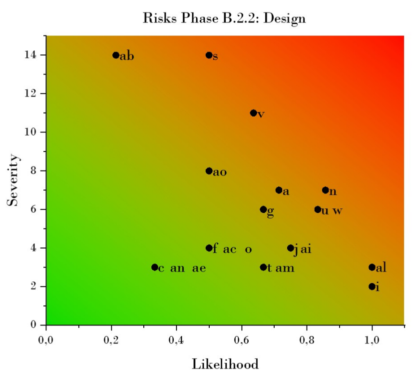
Since the duration of phases B.1.3, B.2.1, B.2.2, B.2.3, B.3.1, B.3.2, B.3.3, G.1, G.2, G.3.1, G.3.2 and G.3.3 depend on the risks, these risks are placed in a risk matrix. The x-axis of these matrices represents the likelihood of the risk. The y-axis represents the severity of the risks on the activity. In each caption of the risk matrix of the activities, the most crucial risks are mentioned. These risks are often the risks in the red and orange area, with a high severity. In Figure 5.2 the risk matrices of phases B.1.3 - G.3.3 are depicted. The other matrices of the phases are in Appendix E. The figures give a clear view of the risks that influence the activities the most. So, for example, Figure 5.2(a) shows that risk ae deviates the most compared to the other risks. This deviation means that when this risk occurs, the impact will be high. So this risk should be prevented for this particular activity. When this risk has to be prevented, it depends on the influence of the stakeholders. When the stakeholders can influence the risk, the risk can be prevented. If this is not the case, the risk cannot be prevented, and maybe other risks can be prevented. If the risk cannot be prevented, and other risks need to be chosen to prevent, the next risk can be determined with the help of the figure. The risks in the orange and red area are all risks with a significant influence on the activity when they occur. Therefore the figure can show clearly which risk needs to prevented next. For the next risks, it is again important to see if the risk can be influence by the stakeholders.



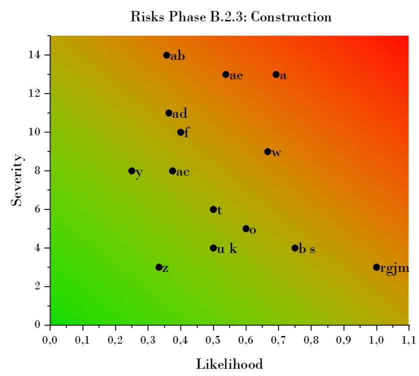
(a) Risk matrix of phase B.1.3, where risks *ae*, *y*, *s* and *z* are the most crucial



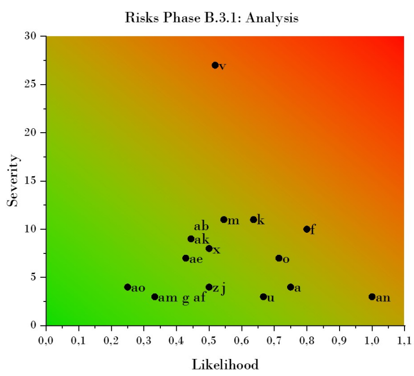
(b) Risk matrix of phase B.2.1, where risks *v*, *am* and *g* are the most crucial



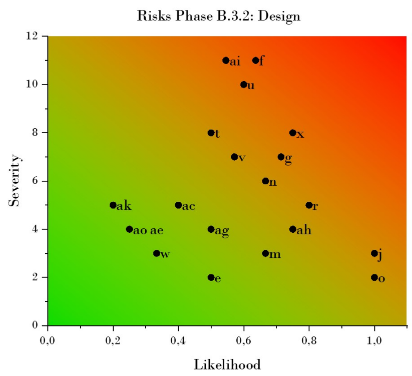
(c) Risk matrix of phase B.2.2, where risks *ab*, *s* and *v* are the most crucial



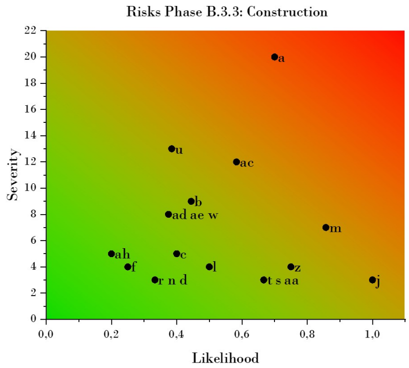
(d) Risk matrix of phase B.2.3, where risks *ab*, *ae* and *a* are the most crucial



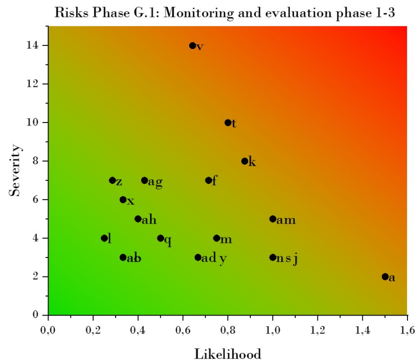
(e) Risk matrix of phase B.3.1, where risk *v* is the most crucial



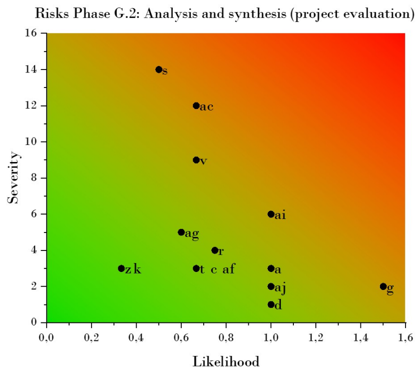
(f) Risk matrix of phase B.3.2, where *ai*, *f*, *y* and *x* are the most crucial



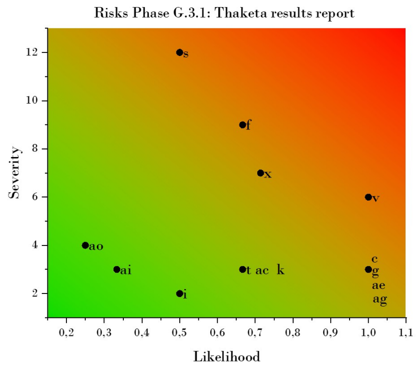
(g) Risk matrix of phase B.3.3, where risk a is the most crucial



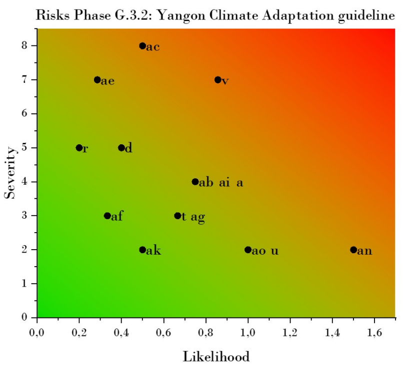
(h) Risk matrix of phase G.1, where risks v and a are the most crucial



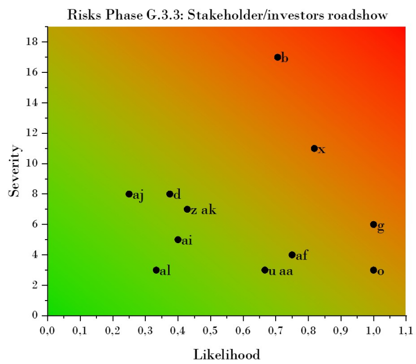
(i) Risk matrix of phase G.2, where risks s, ac and g are the most crucial



(j) Risk matrix of phase G.3.1, where risks s, f, x and v are the most crucial



(k) Risk matrix of phase G.3.2, where risks ae, ac, v and an are the most crucial



(l) Risk matrix of phase G.3.3, where risks b, x and g are the most crucial

Figure 5.2: Risks matrices of phase B.1.3 - G.3.3

5.2 Monte-Carlo simulation

The simulation model simulates the duration of the activities according to their distributions. The most realistic duration ($mode$), optimistic duration (min) and pessimistic duration (max), according to the simulation model, are shown in Table 4.1. With the help of Formula 2.7 and Formula 2.9, $\mathbb{E}(T)$ and $var(T)$ are calculated per activity and placed in the table. As phases A, B.1.1, B.1.2, C, D, E, F and G.4 do not influence the total duration of the project, mentioned in Section 5.1.1, they do not have these parameters and are therefore not included in this table. Each activity also has an error, which means that the duration of an activity can deviate. This error is also added in the table.

Table 5.3: The duration of the activities according to the simulation model

Phase	**min**	**mode**	**max**	$\mathbb{E}(T)$	$var(T)$	σ_T
B.1.3	25	79	156	82.83	476.7	21.83
B.2.1	27	82	118	78.83	230	15.17
B.2.2	21	29	63	30.33	49	7.00
B.2.3	34	80	111	77.5	164.7	12.83
B.3.1	26	51	102	55.33	160.4	12.67
B.3.2	22	28	57	31.8	34	5.83
B.3.3	21	59	109	61	215.1	14.67
G.1	216	259	320	262	300.4	17.33
G.2	81	130	182	130.5	283.4	16.83
G.3.1	11	25	82	32.17	140	11.83
G.3.2	15	41	112	48.5	261.4	16.17
G.3.3	76	112	169	115.5	240.3	15.5

The most realistic duration of the project is 520 working days (the end date of the project is 23-08-2021), which is significantly more than the planned 412 working days. The most optimistic duration takes 406 working days (the end date of the project is 08-02-2022), and the most pessimistic duration takes 641 working days (the end date of the project is 18-07-2022). The distribution of the project duration is depicted in Figure 5.3, with $\alpha = 10.88$ and $\beta = 11.32$. The graph is a little bit skewed to the right as $114 < 121$.

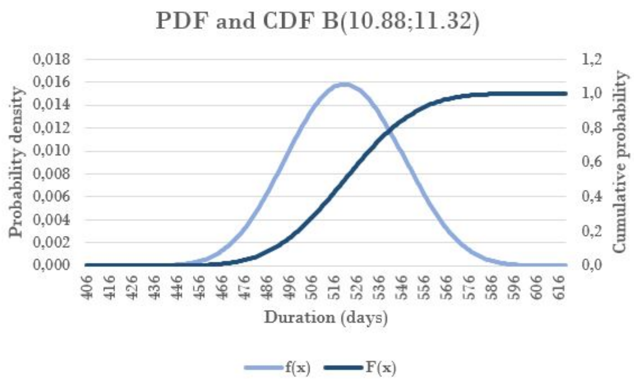


Figure 5.3: Distribution project duration

The minimum duration (optimistic duration) of the whole project is 406 working days, which is less than the planned duration of the project. As the pessimistic duration is more than the planned duration, different scenarios are analysed to determine if the reduction of several risks for a given activity can influence the total project duration.

The optimistic project duration takes 406 working days. The activities differ in days compared to their planned duration (Table 3.2). They differ from -44 days to +30 working days. The critical path of this scenario is A - B.1.1 - B.1.2 - B.2.2 - B.3.1 - B.3.2 - B.3.3 - G.3.1 - G.3.3 - G.4 and is depicted in Figure 5.4. In this figure, the duration of the activities is mentioned as well. As phases C, D, E and F adjust to the project duration, their duration is deleted in the figure. Phase G.4 is always 22 working days and influences the critical path; as such, this activity duration is added in the figure.

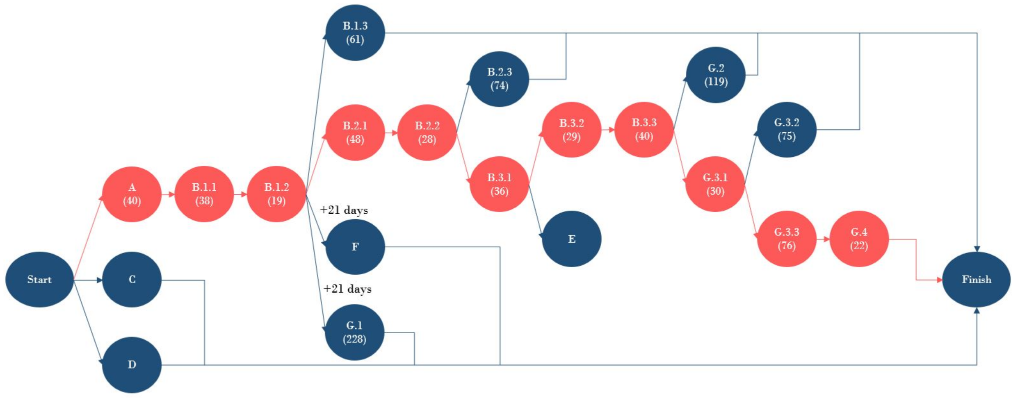


Figure 5.4: Critical path of the optimistic duration

The pessimistic scenario takes 641 working days and has the same critical path as the optimistic duration. The value of the duration of activities are differing from -27 to +59 compared to their planned duration (Table 3.2). The critical path is depicted in Figure 5.5. As the optimistic duration, the duration of phases C, D, E and F are not depicted and G.4 is constant.

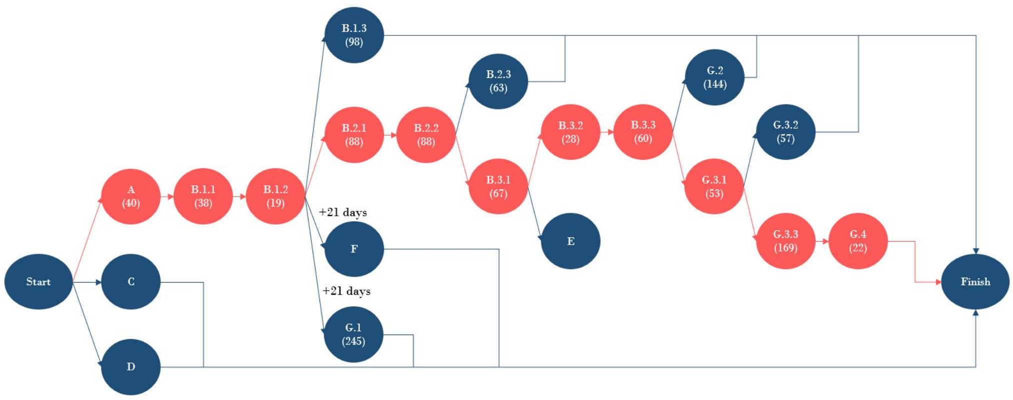


Figure 5.5: Critical path of the pessimistic duration

According to the values of the simulation, there is also an expected time for each activity. The expected time is depicted in Figure 5.6. The total duration of the expected path is 527 working days, and the critical path is the same as the other two scenarios. This expected duration is 115 working days more than the planned duration of 412 working days.

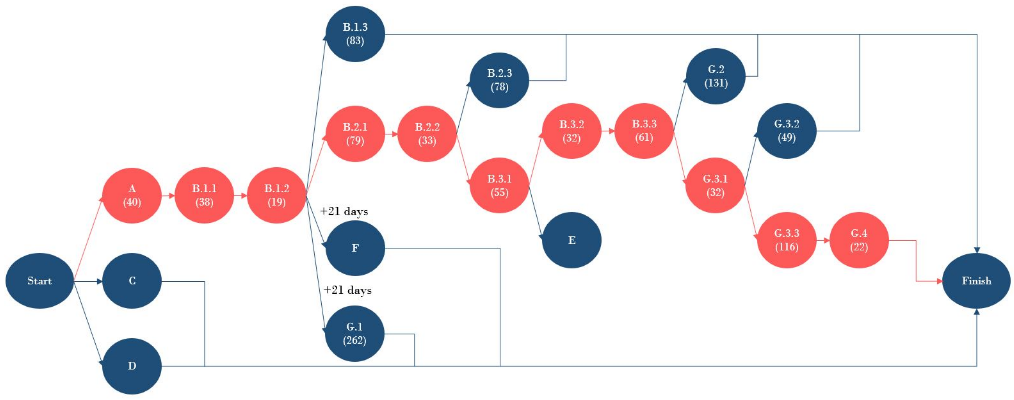


Figure 5.6: Critical path of the expected duration

The CI of each activity is calculated using Formula 2.15 and its distribution. The result of the calculation is that phases B.1.3, B.2.3, C, D, E, F and G.3.2 have a CI of 0, concluding they are never on the critical path. Phases A, B.1.1 and B.1.2 have a CI value of 1, meaning that they always are part of the critical path of the project. Keeping in mind the AON network, Figure 3.2 of Section 3.1.2, the next successor of phase B.1.2 are four other activities, phase B.1.3, B.2.1, F and G.1. Since two out of four phases have a CI of 0, the critical path never chooses these paths. Phase B.2.1 has a CI of 0.94, and Phase G.1 has a CI of 0.06.

Table 5.4: CI value of the activities

Phase	**CI**
A	1
B.1.1	1
B.1.2	1
B.1.3	0
B.2.1	0.94
B.2.2	0.94
B.2.3	0
B.3.1	0.94
B.3.2	0.94
B.3.3	0.94
C	0
D	0
E	0
F	0
G.1	0.06
G.2	0.065
G.3.1	0.875
G.3.2	0
G.3.3	0.875
G.4	0.875

Since phase B.2.2 is an immediate successor of phase B.2.1, and there is no other path to follow after phase B.2.1, phase B.2.2 consist of the same CI value as its predecessor, namely $CI = 0.94$. Phases B.3.1, B.3.2 and B.3.3 all have the same CI value as the predecessors as there is no other path to follow, according to the CI indices. Phase G.2 has a CI value of 0.65 which means that when phase B.3.3 is on the critical path, 6.91% of the cases phase G.2 is also on the critical path, 93.09% of the cases the critical path consists of phases G.3.1, G.3.3 and G.4. These values have a CI value of 0.875. The CI values are all summarised in Table 5.4.

Since the CI index is the most important index for this research, only this index is calculated. With the CI index, it is possible to see to what extent the activities occur on the critical path. Based on this index, it is possible to reduce the risks and the duration of an activity on the critical path. The SSI index cannot be calculated in this research as the σ of the planned duration cannot be calculated. The SI is not calculated as the total float of each activity per iteration must be determined. As such, given the time frame of this research, it is not feasible to calculate this index.

5.3 Scenario analysis

For creating a scenario analysis, different values are needed to determine the analysis. These values can be found in Section 5.1.1 (duration distributions of the activities), Section 5.1.2 (risks of the activities) and Section 5.2, where the distributions of the activities were simulated, and the distribution of the total project was determined.

Since the pessimistic duration takes 641 working days, it is crucial to reduce the pessimistic duration. The duration of the pessimistic estimation is 1,56 times more than the planned duration (641/412). Even the expected duration, according to the simulation, takes 108 days more than the project team planned. Different scenarios can reduce the duration of the project and its activities to reach the milestones.

There are three milestones: the elections, the world water day and the end date of the project mentioned in Section 3.1.3. For the first milestone, the elections, it is crucial that phase B.2.3 is finished before 01-11-2020. For the second milestone, the world water day, phase B.3.3 must be finished before 22-05-2021, and for the last milestone, all the phases must be finished before 31-08-2021.

When the optimistic duration, according to the simulation model, occurs two milestones are not feasible. Phase B.2.3 is finished on 12-01-2021 and phase B.3.3 is finished on 24-02-2021. The end date of the project is feasible as the current end date for the optimistic duration is 23-08-2021.

The expected duration takes 527 working days, which is 115 working days more than the planned duration. None of the milestones is reached because phase B.2.3 is finished on 09-03-2021, phase B.3.3 is finished on 15-06-2021, and the end date is 08-02-2022.

The pessimistic duration, according to the simulation model, takes 641 working days. This duration means that just as the expected duration, all the milestones are not reached. Phase B.2.3 finishes on 02-04-2021, phase B.3.3 finishes on 10-08-2021, and the whole project ends on 18-07-2022. When this duration takes place, it would be horrible for the whole project as its delay is almost a year.

In this research, there are five scenarios researched. The first three scenarios are based on the time estimations mentioned in Section 5.2. As both the expected duration and the pessimistic duration do not reach any milestone, both these durations should be decreased by preventing risks. For the optimistic scenario, only the end date is reached. It is necessary to investigate whether or not this milestone is reached when certain risks are prevented from achieving other deadlines. The fourth scenario is based on preventing the most occurring/common risks. As these risks are appearing a lot, it is interesting to know if preventing these risks will influence the total duration of the project or if it does not influence the duration at all. The fifth scenario is based on the CI values of Table 5.4. Here the most common risks of the activities with the highest CI values are prevented. The activities have a high CI value which means that they often occur on the critical path and are therefore determining the duration of the project. When the risks of these activities are prevented, it is possible that the duration of the whole project is reduced. Therefore this scenario is fascinating to research.

5.3.1 Scenario 1

Scenario 1 is about changing the optimistic duration by decreasing the duration of an activity. With this decreased duration, it is possible to see if the milestones are reached when the risks are prevented. Since two out of three milestones are not being reached in the optimistic scenario, a decrease of delay must take place in the activities that deviate the most compared to their planned duration. Considering there are two activities that deviate much compared to their planned duration, activity B.2.3 and activity G.3.2 should be decreased. However, because these activities are not on the critical path of this scenario, it would not change the duration of the scenario. Therefore other activities must be chosen to decrease their pessimistic duration. These activities must lay on the critical path and should negatively influence the total duration of this scenario. Therefore the activities that are chosen to reduce their pessimistic value are phase B.2.2, phase B.3.2 and phase G.3.1. The first two phases deviate eight days compared to their planned duration, and the last phase deviates ten days compared to its planned duration. The other activities deviate six or fewer days compared to their planned duration.

When the risks of the three activities are compared, six similar risks occur in each activity. These risks are:

1. *ae*
2. *ai*
3. *ac*
4. *f*
5. *t*
6. *ao*

From these risks, three risks can be influenced and can therefore be prevented by the stakeholders. These risks are risk *t*, *f* and *ai*.

Due to confidential issues, the prevention methods of the risks are removed.

When the risks are prevented, the new pessimistic duration is calculated. This new duration is depicted in Table 5.5. The first column represents the activities where the risks are occurring. The second column is the optimistic time estimation, and the third column represents the pessimistic time estimation, both based on Table 5.3. With these values, the difference between the optimistic and pessimistic scenarios are calculated. Next to the differences, the corresponding level of severity of that phase is listed (sum of severity levels). Then, the risks with their severity levels are recorded. Formula 5.1 shows the formula to calculate the new pessimistic duration of an activity with risk x and y.

$$\text{Duration} = \frac{(\text{total severity} - \text{severity } x - \text{severity } y) * (\max - \min)}{\text{total severity level}} + \min \tag{5.1}$$

So in the table, the new pessimistic duration of the activities is determined. This new pessimistic duration is formatted bold.

Table 5.5: New pessimistic duration

Phase	**min**	**max**	**Total severity**	**Risk t**	**Risk f**	**Risk ai**
B.2.2	21	63 **59**	119	3	4	4
B.3.2	22	57 **48**	112	8	11	11
G.3.1	11	82 **65**	64	3	9	3

After performing the simulation of the project, there are new time estimations of the project. The pessimistic duration decreases from 641 working days to 626 working days. The optimistic duration increases from 406 working days to 441 working days and the most realistic duration increases from 520 working days to 531 working days. The distribution function of the project duration is depicted in Figure 5.7. The graph is skewed to the right as $69 < 118$.

Each activity has different values for the optimistic and pessimistic time estimations of this scenario. These values, together with the expected duration of each activity of this scenario, are depicted in Appendix F, Table 2. The optimistic scenario takes 441 days. According to the simulation model, this duration occurs two times. This is depicted as a_1 and a_2 in Table 2 and Table 5.7. The critical path of the first optimistic scenario is A - B.1.1 - B.1.2 - G.1, from both the second optimistic scenario and the pessimistic scenarios the critical path is A - B.1.1 - B.1.2 - B.2.1 - B.2.2 - B.3.1 - B.3.2 - B.3.3 - G.3.1 - G.3.3 - G.4. In the second table it is possible to see whether or not the activities are finished before a given deadline. Normally phase B.2.2 must be finished before deadline 1, phase B.2.3 must be finished before deadline two, and the project deadline is 31-08-2021. In the table, it is possible to see the end dates of the project according to this scenario. It shows that none of the milestones is reached.

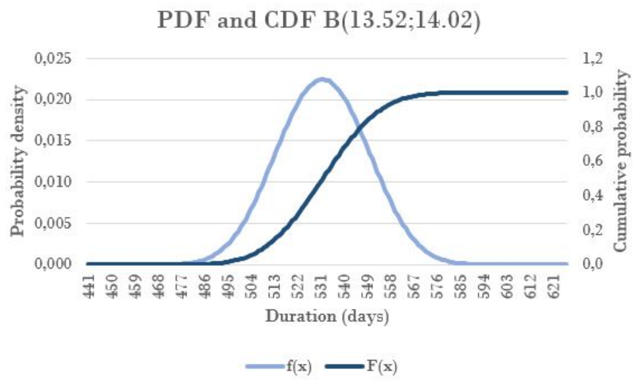


Figure 5.7: Distribution project duration scenario 1

Table 5.6: Finish dates and phases to meet the milestones

	$\min_1$	$\min_2$	max	$\mathbb{E}(x)$
Phase B.2.3	05-01-2021	18-01-2021	13-04-2021	09-03-2021
Phase B.3.3	11-03-2021	12-03-2021	23-09-2021	14-06-2021
End date	11-10-2021	11-10-2021	27-06-2022	07-02-2022

5.3.2 Scenario 2

This scenario focuses on the expected duration according to the simulation model. Each activity has an expected duration (Formula 2.7 of Section 2), and when this expected duration occurs, none of the deadlines is reached. Since there is a difference of +35 until -10 between the expected duration of the activities and their planned duration (Table 3.2), the highest differences should be decreased. There is a difference of +35 working days between the expected duration of phase B.2.1 and its planned duration. Furthermore, there is a difference of +34 working days between the expected duration of phase B.2.3

and its planned duration and the difference between the two durations of phase B.3.3 is +27 working days. Due to these large differences, the risks of these phases should be prevented. The other differences are below 20 and therefore have a less impact.

Between the three activities, there are identical risks. From these risks, the stakeholders can prevent seven risks. These risks are:

1. w
2. m
3. j
4. s
5. f
6. t
7. a

When these risks are prevented there is a new pessimistic duration of the activities. *Due to confidential issues, the prevention methods of the risks are removed.*

The values to calculate the new pessimistic duration are depicted in Appendix F Table 3. The new pessimistic duration of phase B.2.1 takes 107 working days, phase B.2.3 takes 82 working days, and phase B.3.3 takes 76 working days.

The simulation model simulated the project with these new durations. The new optimistic scenario takes 444 working days, the new pessimistic scenario takes 601 working days, and the most realistic time estimation takes 512 working days. The new distribution of the project duration is depicted in Figure 5.8. The duration of the activities are stated in Appendix F Table 4. Both paths are following the same critical path: A - B.1.1 - B.1.2 - B.2.1 - B.2.2 - B.3.1 - B.3.2 - B.3.3 - G.3.1 - G.3.3 - G.4. As Table 5.7 shows, none of the milestones is reached when these risks are prevented for activities B.2.1, B.2.3 and B.3.3. Nevertheless, the end date is reduced compared to the first simulation model (the pessimistic duration is reduced).

Table 5.7: Finish dates and phases to meet the milestones

	min	max	$\mathbb{E}(x)$
Phase B.2.3	25-01-2021	30-03-2021	03-03-2021
Phase B.3.3	06-04-2021	16-07-2021	08-06-2021
End date	14-10-2021	09-05-2022	26-01-2022

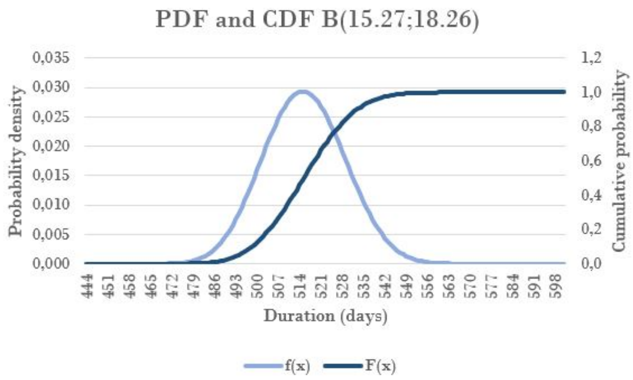


Figure 5.8: Distribution of the project duration of scenario 2

5.3.3 Scenario 3

In this scenario, the pessimistic duration of the simulation model is taken into account. Based on the critical path and the deviation of the duration of the pessimistic duration and the planned duration, three activities are chosen to reduce their pessimistic duration. Phase B.2.1 deviates 44 working days, phase G.3.1 deviates 33 working days, and phase G.3.3 deviates 59 working days. Four risks can be influenced by the stakeholders when the risks of the three activities are compared. The project team and the stakeholders cannot influence the other corresponding risks. The four risks that will be reduced are:

1. *ai*
2. *af*
3. *f*
4. *v*

When these risks are prevented, there is a new pessimistic duration of the activities (explained in Section 5.3.1, Table 5.5).

Due to confidential issues, the prevention methods of the risks are removed.

These pessimistic durations are for phase B.2.1 90 working days, for phase G.3.1 62 working days and for phase G.3.3 159 working days. The corresponding table with the values needed to calculate the new duration can be found F Table 5.

When the simulation is simulated with the new pessimistic duration of the activities, the new optimistic duration takes 453 working days. The new pessimistic duration takes 593 working days, and the most realistic time estimation takes 514 working days. The corresponding distribution of the project duration can be found in Figure 5.9. The simulation results of the duration of the activities are shown in Appendix F Table 6.

The critical path of both the pessimistic and optimistic duration follows A - B.1.1 - B.1.2 - B.2.1 - B.2.2 - B.3.1 - B.3.2 - B.3.3 - G.3.1 - G.3.3 - G.4. As Table 5.8 shows, none of the deadlines is met.

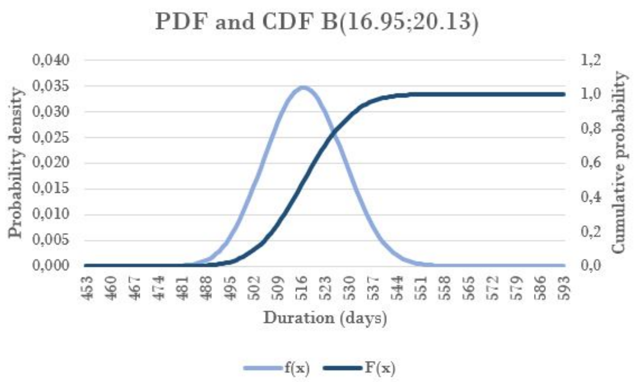


Figure 5.9: Distribution of the project duration of scenario 4

Table 5.8: Finish dates and phases to meet the milestones

	min	max	$\mathbb{E}(x)$
Phase B.2.3	15-01-2021	09-04-2021	09-03-2021
Phase B.3.3	26-03-2021	06-09-2021	11-06-2021
End date	27-10-2021	11-05-2022	28-01-2022

5.3.4 Scenario 4

Scenario 4 is about the most occurring risks. Since all the risks are identified, the top risks of each activity are discussed in Section 5.1.2. The most common risks are:

1. *ae*
2. *z*
3. *v*
4. *a*
5. *x*
6. *an*

Since the stakeholders can influence two risks, risk v and risk a, these risks can be prevented. In total risk v occurs six times, and risk a occurs three times as a critical risk. When the stakeholders are preventing these two risks, the risks will not occur in any activity. A new pessimistic scenario occurs when the risks are prevented. The new pessimistic duration of the activities are shown in Appendix F Table 7.

When the new pessimistic durations are changed with the corresponding optimistic and realistic durations of the simulation model, the simulation will simulate this scenario. The simulation results in a new density function of the duration of the project. The new optimistic duration takes 433 working days, the most realistic duration takes 525 working days, and the pessimistic duration takes 594 working days. The graph is skewed to the left since $92 > 69$. This is depicted in Figure 5.10.

The duration of the activities in each scenario are depicted in Appendix F Table 8. Both the pessimistic and optimistic duration are following the same critical path: A - B.1.1 - B.1.2 - B.2.1 - B.2.2 - B.3.1 - B.3.2 - B.3.3 - G.3.1 - G.3.3 - G.4. Preventing the risks will not result in meeting the deadlines, as is depicted in Table 5.9.

Table 5.9: Finish dates and phases to meet the milestones

	min	max	$\mathbb{E}(x)$
Phase B.2.3	28-01-2021	31-03-2021	01-03-2021
Phase B.3.3	26-02-2021	12-08-2021	09-06-2021
End date	29-09-2021	12-05-2022	04-02-2022

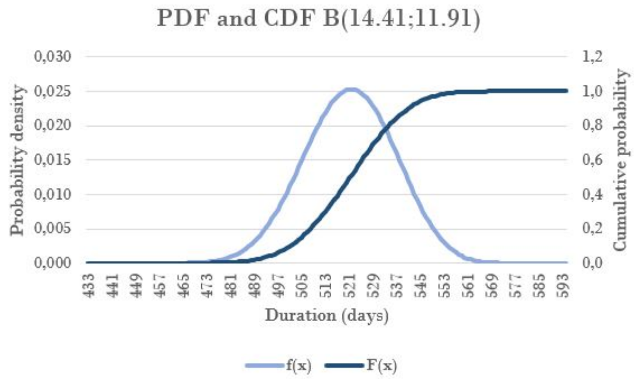


Figure 5.10: Distribution of the project duration of scenario 4

5.3.5 Scenario 5

Scenario 5 is based on the CI values of the activities. There are five activities with a CI value of 0.94. These activities are phase B.2.1, analysis, phase B.2.2, design, phase B.3.1, phase B.3.2 and phase B.3.3. When the pessimistic duration of these activities is reduced, there is a chance that the pessimistic scenario of the duration of the project decreases and the project can meet some milestones. There are some critical risks for each activity which influence their duration. In total, there are 16 risks which have a critical influence on one or more activities. These risks are:

1. *v*
2. *am*
3. *o*
4. *g*
5. *z*
6. *ab*
7. *s*
8. *ao*
9. *ai*
10. *f*
11. *u*
12. *t*

13. *x*
14. *n*
15. *a*
16. *ac*

From this list, seven risks can be prevented by the stakeholders. Risks *v*, *am*, *ai*, *f*, *t*, *n* and a can be prevented.

Due to confidential issues, the prevention methods of the risks are removed.

When these risks are prevented, the pessimistic duration of the five activities is reduced. The schedule used to calculate these durations is depicted in Appendix F Table 9.

When the simulation is simulated with the corresponding new pessimistic durations (F Table 9), the total duration of the project is changed. The new optimistic duration takes 451 working days, there is a new pessimistic duration takes 580 working days, and the new most realistic time estimation takes 505 working days. The distribution of the duration is depicted in Figure 5.11.

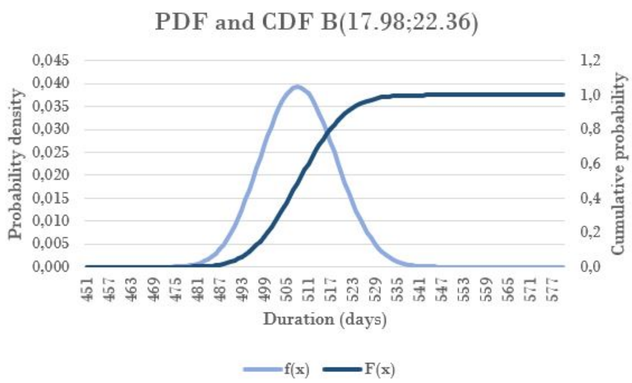


Figure 5.11: Project distribution of scenario 5

The optimistic duration occurs twice in the simulation results. Therefore a column is added to Table 5.10, where both optimistic durations are shown. Each critical path of the three durations (two times optimistic one time pessimistic) is following the same path: A - B.1.1 - B.1.2 - B.2.1 - B.2.2 - B.3.1 - B.3.2 - B.3.3 - G.3.1 - G.3.3 - G.4. As is possible to see in Table 5.10, no deadline is reached, and when the optimistic duration occurs, the project still has a month delay compared to the planned duration of the project team.

Table 5.10: Finish dates and phases to meet the milestones

	$\min_1$	$\min_2$	max	$\mathbb{E}(x)$
Phase B.2.3	17-12-2020	05-01-2021	15-03-2021	24-02-2021
Phase B.3.3	10-03-2021	24-03-2021	05-07-2021	20-05-2021
End date	25-10-2021	25-10-2021	22-04-2022	13-01-2022

5.4 Conclusion

In this chapter, the following research questions are answered:

- What risks influence the duration of the project?
  - What is the impact of the involved risks?
- What solutions can be created to prevent the risks of Project X?
  - What solutions are there to prevent the risks of an activity?
  - How much do these solutions influence the end date of the project?

In Section 5.1.2, the risks that influence each activity are determined. The most critical risks of all the activities are risks v, ac, s, f, a and g as they occur in the red/orange zone of Figure 5.1. There are five scenarios created to answer the second research question. Some solutions to prevent risks are mentioned in these scenarios (*due to confidential issues, the prevention methods of the risks are removed in these sections*). When the risks are prevented in each scenario none of the milestones are being reached and the project does not finish in time.

So solutions that can be created for this project to prevent the risks are the five scenarios, where the first scenario is about decreasing the optimistic duration of the project, the second scenario is about decreasing the pessimistic duration of the project. The third scenario is about decreasing the expected duration of the project. The fourth scenario is about preventing the most occurring risks of the project, and the last scenario is based on the CI value of the activities. Based on this CI value, the risks that should be prevented are determined. For each scenario, the optimistic, pessimistic and estimated end dates of the project were determined. Each scenario does not reach the desired end date of the project (the planned duration) and the difference between the optimistic and pessimistic scenario 185 working days and 129 working days. The first scenario prevents three risks for two activities, scenario two prevents seven risks for three activities, scenario three prevents four risks for three activities, scenario four prevents two risks for all activities, and scenario five prevents seven activities for six activities. Preventing more risks means that it is time-consuming and maybe much money that needs to be invested. However, these preventions can have a significant influence on the duration of the project as when more risks are prevented, the pessimistic duration decreases. The pessimistic duration of scenario 1 and 2 are 1.46 and 1.52 times as long as the planned duration (412 working days). Therefore a pessimistic duration above 600 working days takes too long compared to this planned duration.

Chapter 6

Conclusion, limitations and recommendations

In this chapter, the research is concluded and recommendations are made based on the results of Chapter 5. Also limitations of this research and further research is treated in this chapter. In this thesis, the schedule of Project X was determined and the influence of risks on the activity durations were determined. In this pilot project, several risks can occur, which were identified and added to the distribution of the activities. These risks were taken into account when the participants (stakeholders) of the survey determined the time estimations of the activities. With the optimistic (*min*), pessimistic (*max*) and most likely duration (*mode*), the distributions of the activities were determined. With the help of a Monte Carlo simulation, the duration (*min*, *max*, *mode*) of the activities for the entire project were calculated for 1000 iterations. According to these three durations, a scenario analysis was made where five different scenarios were researched.

6.1 Conclusion

In this project, the research question "*What risks should be prevented to finish Project X in time?*" was studied. In this section, the research question is answered by first answering the sub-questions:

1. Which method can be used to create a risk analysis?
2. What is the current schedule of Project X?
3. What risks influence the duration of the project?
4. What solutions can be created to prevent the risks of Project X?

During this research, the method of Vanhoucke (2013) is used. Four steps were followed:

1. Creating a baseline schedule with a network diagram.
2. Identifying the risks and the probability distributions.
3. Creating a Monte-Carlo simulation to get an overview of the duration of the project.
4. Identifying the simulation outputs with sensitivity indices.

The baseline schedule is the schedule that is the basis of the project. With the baseline schedule, a comparison can be made with the current ongoings. Also, it is possible to see if the project is following the baseline schedule or if delays are occurring. In this research, the PERT model was used. It is assumed that the activities follow a beta PERT distribution, where the *min*, *mode* and *max* were determined with the help of a survey sent to the stakeholders. The level of the risks was determined with their likelihood and their severity. The stakeholders determined the severity and the level of the risks by appointing risks to activities. A simulation model was used to simulate the activities with their distributions. With the help of this simulation model, the schedule of the project was constructed. The criticality index was used to determine the number of activities that are on the critical path for each iteration. The current schedule consists of six different phases that concern twenty activities. Phases B and G contain sub-phases, whereas the other four phases consist of just one activity. All the activities are interwined, so when one activity is delayed, other activities start later than planned. There are three milestones: the elections (01-11-2020), the world water day (22-03-2021) and the delivery date of the project (31-08-2021). Before the first milestone, phase B.2.3, must be finished. Additionally, phase B.3.3, has to be completed before the second milestone, and lastly, before the third milestone, the whole project must be finished. The currently planned schedule of the project is depicted in Figure 3.1, in Chapter 3.

In total, 41 risks can occur during the project. These risks are noted in Table 5.2, in Section 5. The frequency of the risks is depicted in Figure 6.1. As this figure shows, the most occurring risks, are risks *f*, *g* and *s*. The stakeholders can prevent some risks, others cannot be prevented beforehand; for example, the large distance between the consortium members. According to the risk matrix of Section 5.1, risks *v*, *ac*, *s*, *f*, *a* and *g* have the most influence on the whole project when there occurs a delay as their risk ratings are higher than the other risks.

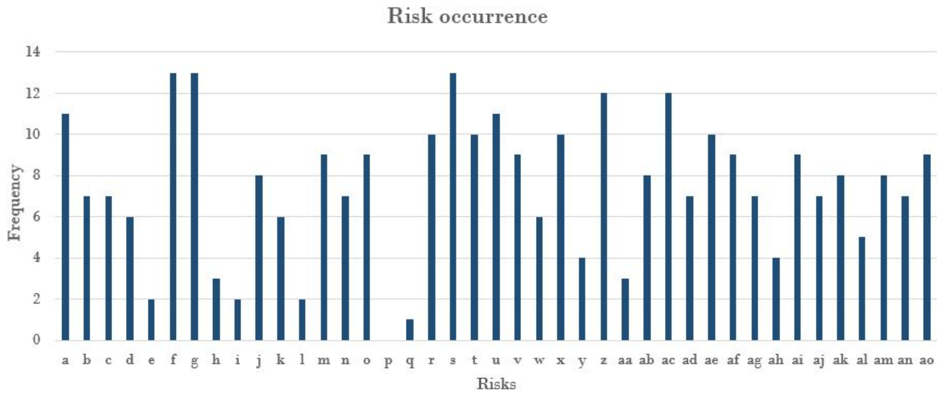


Figure 6.1: Risk occurrence, where risks *f*, *g* and *s* are the most frequently mentioned risks by the stakeholders concerning all activities

The simulation model is based on the values determined by the stakeholders (*min*, *mode* and *max*). The distribution of the activities was calculated, and with the simulation, realistic values were linked to the activities, these values, according to the simulation model, can be found in Table 5.1. According to the simulation, the optimistic duration of the project takes 406 working days and only the third milestone is reached. For the pessimistic (641 working days) and most realistic durations (520 working days), none of the milestones are reached. As these values show, the project is finished later than planned.

Five scenarios were studied to investigate if prevention of certain risks can have a positive influence on the duration of the project, meaning that the project can finish in time and reach all the milestones. These values are summarised in Table 6.1, where the *min*, *max* and *mode* respectively represent the optimistic, pessimistic and realistic duration in working days. In each of the 5 scenarios different situations were studied. In 4 out of 5 scenarios risk *f* should be prevented, in 3 out of 5 scenarios risks *t*, *ai*, *a* and *v* should be prevented as these risks have the most influence on the activities for that scenario. These risks can be prevented in different ways.

Table 6.1: The number of days of each scenario

Scenario	min	mode	max	Reaching milestones?
1	441	531	626	No
2	444	512	601	No
3	453	514	593	No
4	433	525	594	No
5	451	505	580	No

As Table 6.1 shows, none of the milestones are reached and the project never finishes in time. So in none of the simulation runs the project duration is equal to the planned project duration. Even when certain risks are prevented and the pessimistic duration of the activities are reduced, the project cannot finish in time according to the current scenarios. This indicates that, according to the simulations, the planned duration of the project is too optimistic and can never be reached in these five scenarios, independent of the prevented risks.

6.2 Limitations and further research

In this section, the limitations of the research are described together with recommendations for further research. First, the limitations will be discussed, then further research will be explained.

6.2.1 Limitations

One limitation during this research was the simulation model, which was made in Microsoft Excel. The simulation was made as such that when there were two or more critical paths, both could not be added to the simulation, and one was chosen. When two or more paths were critical, one of them was added to the desired sheet, the other ones were never investigated. This causes that the CI value of the activities can deviate from the current CI values, also some durations are therefore not included in the analysis.

Another limitation concerns the innovation of the project. Project X is a new innovative project and as mentioned in the name a pilot project, indicating that this was not done before by other companies and that no data was known on how the activities/phases should be developed. As a result, there was no prior knowledge that could be taken into account in the development of the risk analysis for this project, whereas this is the case for most other projects. The data in this thesis was obtained from the stakeholders and they used their expertise to determine the realistic, optimistic and pessimistic time estimations of the activities.

Another limitation is that, because the stakeholders are involved in the project, they are biased which can lead to them filling out the survey more positive (or negative) than it actually is. The influence this limitation can have is that the realistic project duration deviates from the project duration of the simulation. When there is no bias, the project duration can be determined more precisely.

6.2.2 Further research

This research was focused on the activities of Project X. Involving the cost of the project and the influence of the delay on the cost of the project can be appealing as the stakeholders can react to these outcomes as well. Further research can be about these costs. Taking into account the activities and the costs can be very useful for the stakeholders. The available resources can also be used for further studies. When there is a delay, more workers can be employed to attempt to prevent the delay in the intervention and implementation phases.

Combining these three elements would give the stakeholders a better overview with better insights into the risks that influence the project.

Additionally, only five scenarios were evaluated due to time limitations. In further research, more scenarios as well as the current scenarios can be investigated. The current scenarios can be researched more in-depth, so the duration of the project can be reduced when, for example more risks are prevented. It has to be said that it is not guaranteed that reducing the risks will reduce the duration of the project significantly.

When there is more time, the SI (significance index) value can be calculated. Based on this index, a new scenario can be developed to see whether or not this index has a significant influence on the duration of the project when it is reduced.

The stakeholders mentioned new risks that activities can face. These were not taken into account when the risk analysis was made, because the severity and the rate of the risks were not classified. Therefore, it was not possible to take these risks into account when the risk analysis was made. Next time, these risks can be included in the survey and the respondents can add these risks, in a similar fashion as the main risks identified in Section 5.1.2, to the activities.

6.3 Recommendations

In all the research scenarios, none of the milestones were being reached, however, even if the milestones are not being reached, reducing the duration of the activities by preventing risks is recommended. The planned duration of the project is 412 working days. If none of the scenarios is followed, the most optimistic time of the project according to the simulation is 406 working days, the pessimistic duration takes 641 working days and the most realistic duration will be 520 working days. Because of the enormous difference between the optimistic duration and the pessimistic duration (235 working days), it is recommended to decrease the activity durations by preventing their risks. This can decrease the most realistic time estimation and the difference of the two extreme durations (optimistic and pessimistic estimations). Five scenarios were studied in this research, the first three scenarios are: prevention of risks for the optimistic duration, the most realistic duration and the pessimistic duration. Scenario 4 compares the risks that occur in the project and their severities. Scenario 5 compares the risks of the activities with the highest CI value and the risks that are occurring the most in these activities.

In scenario 1 the pessimistic duration of the project is reduced by 15 working days, by preventing certain risks, compared to the first simulation. Both the most realistic duration and optimistic duration are increased. Therefore it is not recommended to follow this scenario. Scenario 2 has a pessimistic duration of 601 working days and is therefore also not recommended as this difference compared to the planned duration is too significant (1.46 times more). Three scenarios dive below 600 working days in the most pessimistic duration of the project, namely, scenario 3, 4 and 5. If the project manager decides to choose a scenario to follow, one of these three scenarios is recommended, as in the worst case scenario, the duration of the project is less than 600 working days.

The difference between the pessimistic and optimistic estimations of scenario 3 is 140 working days, with a most realistic duration of 514 working days. Four risks should be prevented for three activities: risks *af*, risk *v*, risk *f* and risk *ai* should be prevented for phases B.2.1, G.3.1 and G.3.3.

The difference between the pessimistic and optimistic estimations of scenario 4 is 161 working days, whereas the most realistic duration takes 525 working days. Two risks should be prevented for all activities, these two risks are risk *v* and risk *a*.

In scenario 5, the difference between the pessimistic and optimistic estimations is 129 working days, with a most realistic duration of 505 working days. Seven risks should be prevented for five different activities to reach these values. The seven risks are risks v, am, ai, f, t, n and a. The risks should be prevented for phases B.2.1, B.2.2, B.3.1, B.3.2 and B.3.3.

From these three scenarios, scenario 3 has an optimistic duration of 543 days, which is the highest duration of scenarios 3, 4, and 5. Therefore, this scenario is not recommended. When the project manager wants to prevent the least number of risks, scenario 4 should be chosen. The realistic duration takes 525 working days, which is higher than the scenario 5, but the pessimistic duration is still below 600 working days. Only, risks should be prevented for all activities. However, the most realistic duration of scenario 5 is the smallest of all scenarios, just as the pessimistic duration. When the project manager wants to have a small realistic and pessimistic duration, scenario 5 is recommended as these values are smaller than the other scenarios. One thing to keep in mind is that seven risks should be reduced, for five activities in total, which is a significant amount of work, and in this scenario there are a lot of risks that need to be prevented.

Bibliography

About The Water Agency. (n.d.). Retrieved from https://thewateragency.com/about.html

Aggarwa, R., & Ranganathan, P. (2019). Study designs: Part 1 – An overview and classification. *Perspectives in Clinical Research*, *10*(2), 91-94. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6176693/?report=printable doi: 10.4103/picr.PICR

Assaad, R., El-Adaway, I., & Abotaleb, I. (2020). Predicting Project Performance in the Construction Industry. *2020 American Society of Civil Engineers*. (https://doi.org/10.1061/(ASCE)CO.1943-7862.0001797)

Aurora, J. (2012). *Introduction to optimum design* (3rd ed.). Academic Press. (https://doi.org/10.1016/B978-0-12-381375-6.00033-4)

Barreras, A. (2011). *Risk management: Monte Carlo simulation in cost estimating.* Project Management Institute.

Bhatia, M. (2018, September). *Your Guide to Qualitative and Quantitative Data Analysis Methods.* Retrieved from https://humansofdata.atlan.com/2018/09/qualitative-quantitative-data-analysis-methods/#Analyzing_Qualitative_Data

Bonate, P. (2001, 02). A Brief Introduction to Monte Carlo Simulation. *Clinical pharmacokinetics*, *40*, 15-22. doi: 10.2165/00003088-200140010-00002

Chen, J. (2020, February). *Risk Averse.* Retrieved from https://www.investopedia.com/terms/r/riskaverse.asp

Conant, D. D. (2018). Examining critical and near-critical paths: an Excel-based classroom exercise. *Journal of Education for Business*, *93*(6), 285–291. doi: 10.1080/08832323.2018.1490685

Cooper, D., & Schindler, P. (2014). *Business Research Methods* (12th ed.). Mc Graw-Hill/Irwin.

Dan Reid, R., & Sanders, N. (2010). *Operations Management* (3rd ed.). Wiley 2010.

De Marco, A. (2011). *Project management for facility construction.* Springer.

Dictionary. (n.d.). *Force majeure.* Retrieved from https://financial-dictionary.thefreedictionary.com/force+majeure

Driels, M. R., & Shin, Y. S. (2004). Determining the number of iterations for Monte Carlo Simulations of weapon effectiveness. *Naval Postgraduate School, Dept. of Mechanical & Astronautical Engineering*, 15. doi: 10.1109/37.642974

Fahmy, A., Hassan, T., & Bassioni, H. (2014, 05). What is Dynamic Scheduling? *PM World Journal*, *3*.

Ghosh, S., & Jintanapakanont, J. (2004, November). Identifying and assessing the critical risk factors in an underground rail project in thailand: a factor analysis approach. , 633-643. (https://doi.org/10.1016/j.ijproman.2004.05.004)

Hahn, E. D. (2008). Mixture densities for project management activity times: A robust approach to PERT. *European Journal of Operational Research*, *188*(2), 450–459. doi: 10.1016/j.ejor.2007.04.032

Hajdu, M., & Bokor, O. (2014). The Effects of Different Activity Distributions on Project Duration in PERT Networks. *Procedia - Social and Behavioral Sciences*, *119*(March), 766–775. doi: 10.1016/j.sbspro.2014.03.086

Heerkens, J., & van Winden, A. (2017). *Solving Managerial Problems Systematically* (1st ed.). Noordhof Uitgevers bv.

Kandaswamy, S. (2001). The basics of Monte Carlo simulation: a tutorial. *Project Management Institute Annual Seminars Symposium*.

Kaya, G. K., Ward, J., & Clarkson, J. (2019). A Review of Risk Matrices Used in Acute Hospitals in England. *Risk Analysis: An International Journal*, *39*(5), 1060 - 1070. doi: 10.1111/risa.13221

Kelly, K., Clark, B., Brown, V., & Sitzia, J. (2003, 05). Good practice in the conduct and reporting of survey research. *International Journal for Quality in Health Care*, *15*(3), 261-266. Retrieved from https://doi.org/10.1093/intqhc/mzg031 doi: 10.1093/intqhc/mzg031

LexisNexis. (n.d.). *Economic Risk — What Is It and How to Effectively Manage It.* Retrieved from https://www.lexisnexis.com/en-us/products/entity-insight/economic-risk.page

Liberty, D. (2019, January). *5 Techniques to Take Your Data Analysis to Another Level.* Retrieved from https://www.sisense.com/blog/5-techniques-take-data-analysis-another-level/

Ma, D. (2016, April). *Introducing the beta distribution.* Retrieved from https://actuarialmodelingtopics.wordpress.com/2016/04/10/introducing-the-beta-distribution/

Mandal, P. (2018, February). *Tables Statistics.* (Statistics)

Middleton, F. (2019, July). *Reliability vs validity: what's the difference?* Retrieved from https://www.scribbr.com/methodology/reliability-vs-validity/

O'Cull, H., Souroy, A., Motwani, D., R.N.and Magdalin, Boyes, L., & Power, K. (2011). *Method and system for generating a timeline associated with a project schedule* (Vol. 2) (Nos. US 7,921,026 B2).

Oxford University. (2020). *Baseline.* Retrieved from https://www.oxfordlearnersdictionaries.com/definition/english/baseline?q=baseline

Project Management Institute. (2013). *A Guide to the Project Management Body of Knowledge* (5th ed.). Project Management Institute, Inc.

Raftery, J. (1994). *Risk analysis in project management.* E FN Spon.

SCRUM. (2017). *A guide to the SCRUM body of knowledge* (3rd ed.). SCRUMstudy.

Segal, T. (2019, august). *Operational risk.* Retrieved from https://www.investopedia.com/terms/o/operational_risk.asp

Statistics, Data Mining, and Machine Learning in Astronomy: A Practical Python Guide for the Analysis of Survey Data (STU - Student edition ed.). (2014). Princeton University Press.

Technopedia. (2017, February). *Random Number Generator (RNG).* Retrieved from https://www.techopedia.com/definition/9091/random-number-generator-rng

Vanhoucke, M. (2013). *Project Management with Dynamic Scheduling* (2nd ed.). doi: 10.1007/978-3-642-40438-2

Vanhoucke, M. (2016). *Integrated Project Management Sourcebook* (1st ed.). Springer International Publishing. (url=https://doi.org/10.1007/978-3-319-27373-0)

Votto, R., Lee Ho, L., & Berssaneti, F. (2020). Applying and Assessing Performance of Earned Duration Management Control Charts for EPC Project Duration Monitoring. *2020 American Society of Civil Engineers*. (http://doi.org/10.1061/(ASCE)CO.1943-7862.0001765)

Winston, W. (2004). *Operations research* (4th ed.). Cengage Learning.

Yang, Z. Y., & Wang, Z. F. (2010). Comparison between AON and AOA network diagrams. *Proceedings - 2010 IEEE 17th International Conference on Industrial Engineering and Engineering Management, IE and EM2010*, 1507-1509. doi: 10.1109/ICIEEM.2010.5646036

Yeganeh, F., & Zegordi, S. (2019, September). A multi-objective optimization approach to project scheduling with resiliency criteria under uncertain activity duration. *Springer Science+Business Media*. (https://doi.org/10.1007/s10479-019-03375-z)

Appendices

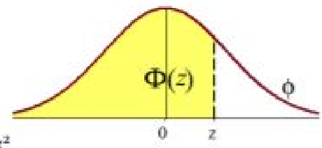
A Distribution function

Standard normal probabilities

The table gives the distribution function Φ for a N(0,1)-variable Z

$$\Phi(z) = P(Z \leq z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{-\frac{x^2}{2}}\, dx$$

Last column: N(0,1)-density function (z in 1 dec.): $\varphi(z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}}$



	Second decimal of z										
z	**0.00**	**0.01**	**0.02**	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**	**φ(z)**
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359	0.3989
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753	0.3970
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141	0.3910
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517	0.3814
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879	0.3683
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224	0.3521
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549	0.3332
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852	0.3123
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133	0.2897
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389	0.2661
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621	0.2420
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830	0.2179
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015	0.1942
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177	0.1714
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319	0.1497
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441	0.1295
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545	0.1109
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633	0.0940
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706	0.0790
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767	0.0656
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817	0.0540
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857	0.0440
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890	0.0355
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916	0.0283
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936	0.0224
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952	0.0175
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964	0.0136
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974	0.0104
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981	0.0079
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986	0.0060
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990	0.0044
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993	0.0033
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995	0.0024
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997	0.0017
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998	0.0012
3.5	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.0009
3.6	0.9998	0.9998	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.0006

Figure 2: Z-value of statistics (Mandal, 2018)

B Survey

Censored!

Censored!

Censored!

B.1 Consent statement

C Survey results

Figure 3: Severity (S) and level of the ratings (L) answered by the respondents phase B.1.3

Figure 4: Severity (S) and level of the ratings (L) answered by the respondents phase B.2.1

Figure 5: Severity (S) and level of the ratings (L) answered by the respondents phase B.2.2

Figure 6: Severity (S) and level of the ratings (L) answered by the respondents phase B.2.3

Figure 7: Severity (S) and level of the ratings (L) answered by the respondents phase B.3.1

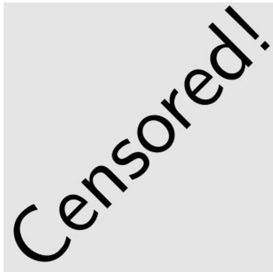


Figure 8: Severity (S) and level of the ratings (L) answered by the respondents phase B.3.2

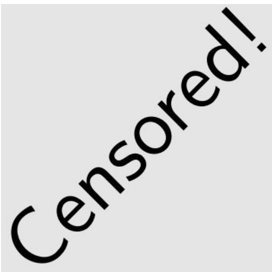


Figure 9: Severity (S) and level of the ratings (L) answered by the respondents phase B.3.3

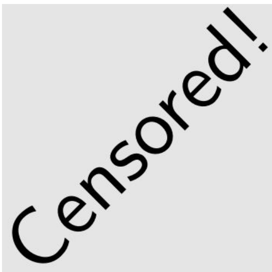


Figure 10: Severity (S) and level of the ratings (L) answered by the respondents phase C

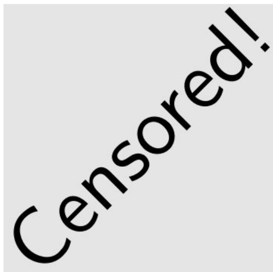


Figure 11: Severity (S) and level of the ratings (L) answered by the respondents phase D

Figure 12: Severity (S) and level of the ratings (L) answered by the respondents phase E

Figure 13: Severity (S) and level of the ratings (L) answered by the respondents phase F

Figure 14: Severity (S) and level of the ratings (L) answered by the respondents phase G.1

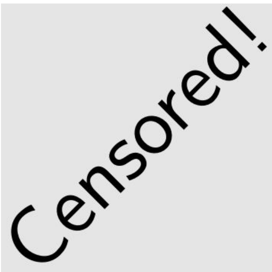


Figure 15: Severity (S) and level of the ratings (L) answered by the respondents phase G.2

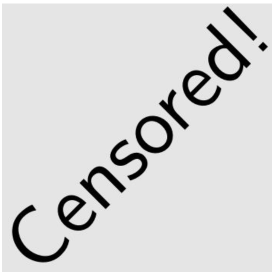


Figure 16: Severity (S) and level of the ratings (L) answered by the respondents phase G.3.1

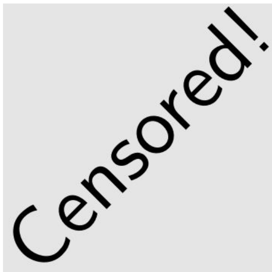


Figure 17: Severity (S) and level of the ratings (L) answered by the respondents phase G.3.2

Figure 18: Severity (S) and level of the ratings (L) answered by the respondents phase G.3.3

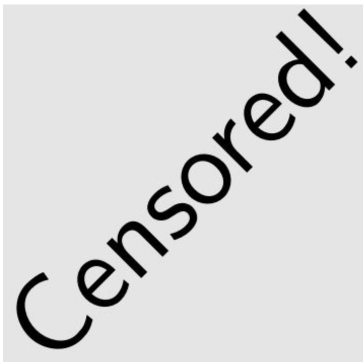


Figure 19: Severity (S) and level of the ratings (L) answered by the respondents phase G.4

B.1.3			B.2.1			B.2.2			B.2.3			B.3.1			B.3.2		
a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b
44	64	86	54	64	86	30	42	54	55	79	79	65	79	79	35	35	66
44	64	86	54	64	74	20	20	30	44	65	79	44	65	65	21	21	44
86	143	183	44	64	104	42	64	85	50	79	119	65	76	99	21	35	66
			21	21	44	20	20	42							21	21	35
21	44	64	21	21	44		20	42	44	22	55	22	44	44	21	35	35
86	108	143	74	86	119	42	64	85	65	79	99	65	76	79	32	35	55
44	64	64	64	86	129	85	85	85	119	119	119	119	119	119	75	75	75
44	64	86	44	44	44	20	20	30	44	44	65	44	44	65	21	21	66
64	64	86	64	64	86												
64	86	86	54	64	74	20	42	42	44	65		44	65	79	32	35	55
44	64	64	44	44	54	20	20	30	34	44	44	44	44	55	21	21	32
64	64	143	74	86	129	42	64	85	79	99	119	99	119	119			
64	86	129	64	86	86	20	42	64	55	79	109	44	79	88	21	35	75

B.3.3			G.1			G.2			G.3.1			G.3.2			G.3.3		
a	m	b	a	m	b	a	m	b	a	m	b	a	m	b	a	m	b
54	77	110	316	337	337	142	152	174	43	43	86	66	66	110	132	132	175
34	34	45	272	272	316	130	130	152	20	15	31	45	45	66	110	132	132
			228	272	337				46	65	108	45	66	131	80	110	197
14	14	99	250	250	250	108	108	118	10	20	20	23	23	45	88	88	98
34	54	54	250	250	272	130	130	130	10	20	31	45	45	45	110	110	110
54	77	99	228	272	294	130	152	162	46	65	81	61	65	88	132	154	175
119	119	119				130	174	195	20	20	20	45	45	45	110	110	110
34	54	99	272	272	272	130	130	130	20	20	46	45	65	65	110	132	175
45	54	77	185	228	272	65	108	130	20	43	55	45	65	88	65	110	132
34	34	45	272	272	272	130	130	130	20	20	31	35	45	11	110	110	110
						65	108	108	55	65	108	56	65	88	110	132	175
54	77	120	272	272	337	130	130	195	108	108	108	88	88	110	110	110	154

Figure 20: Duration of the activities answered by the respondents

D Distributions of the activities according to the simulation model

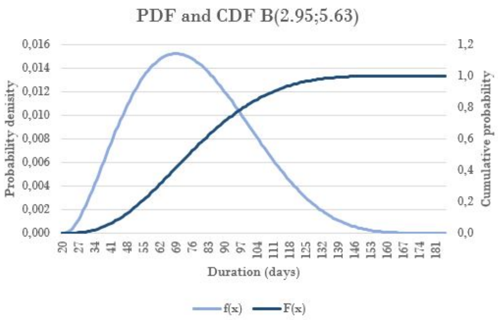


Figure 21: Distribution phase B.1.3 - skewed to the right

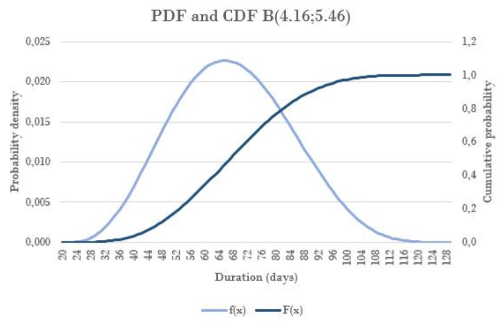


Figure 22: Distribution phase B.2.1 - skewed to the right

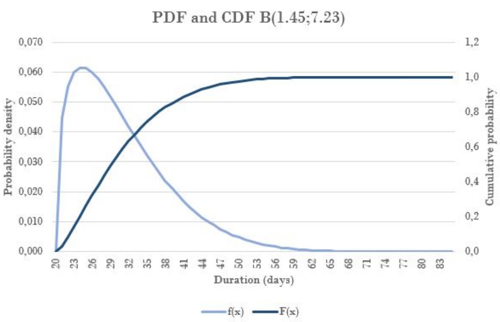


Figure 23: Distribution phase B.2.2 - skewed to the right

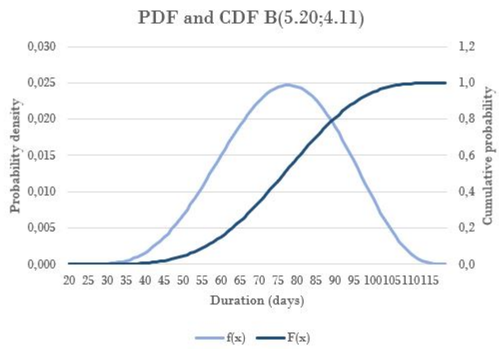


Figure 24: Distribution phase B.2.3 - skewed to the left

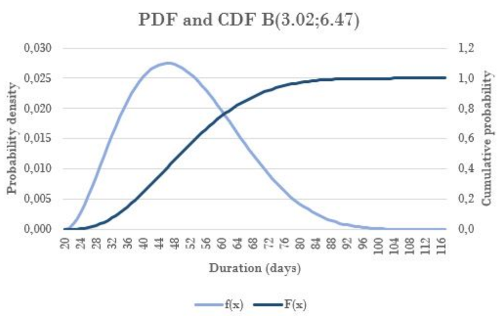


Figure 25: Distribution phase B.3.1 - skewed to the left

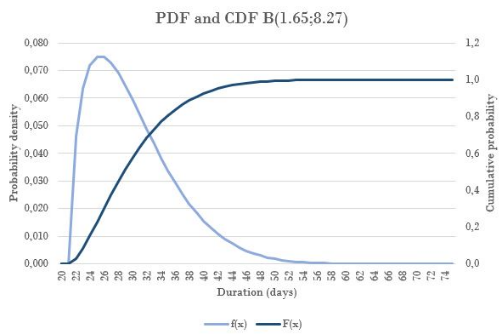


Figure 26: Distribution phase B.3.2 - skewed to the right

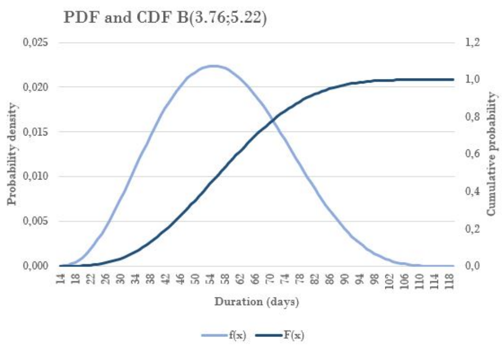


Figure 27: Distribution phase B.3.3 - skewed to the right

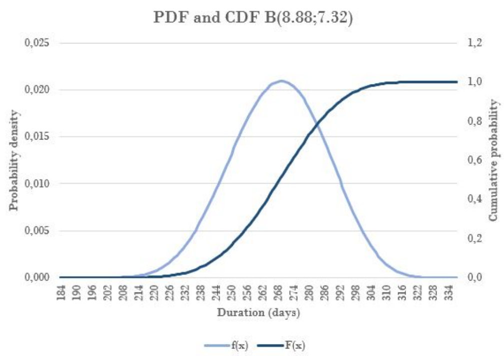


Figure 28: Distribution phase G.1 - skewed to the left

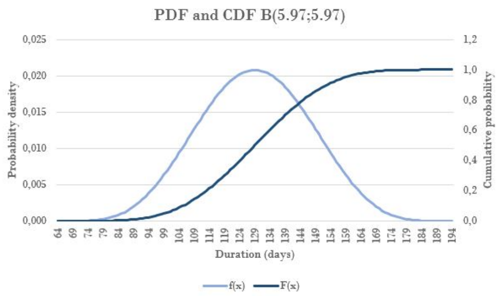


Figure 29: Distribution phase G.2 - skewed normal

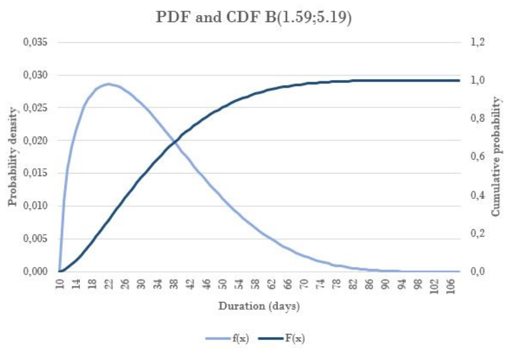


Figure 30: Distribution phase G.3.1 - skewed to the right

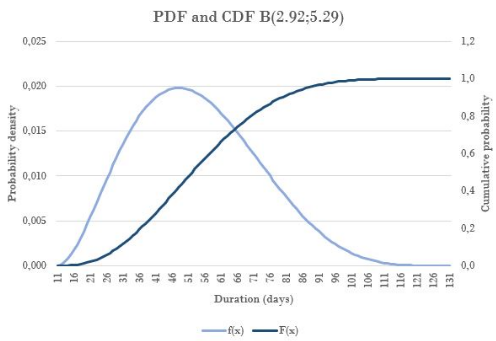


Figure 31: Distribution phase G.3.2 - skewed to the right

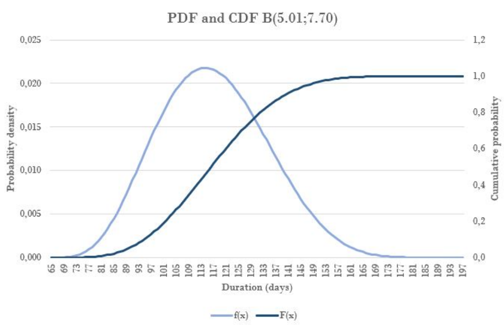
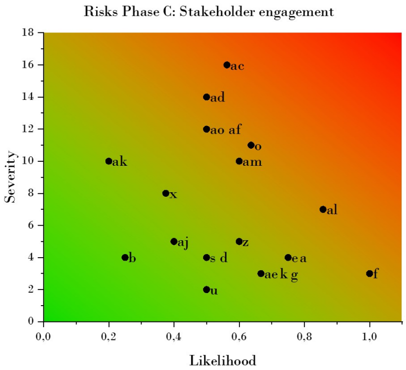
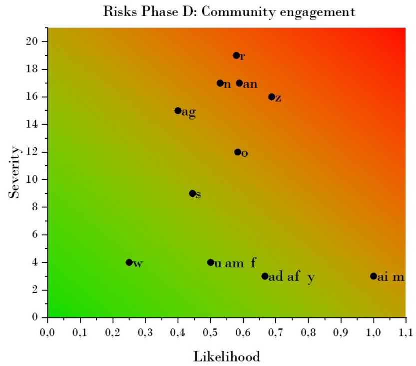


Figure 32: Distribution phase G.3.3 - skewed to the right

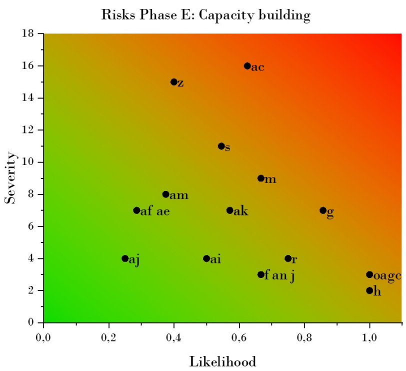
E Risks of phases C, D, E, F and G.4



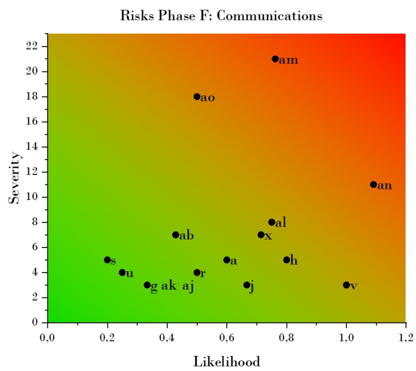
(a) Risk matrix of phase C where risk risk *ac* is the most crucial



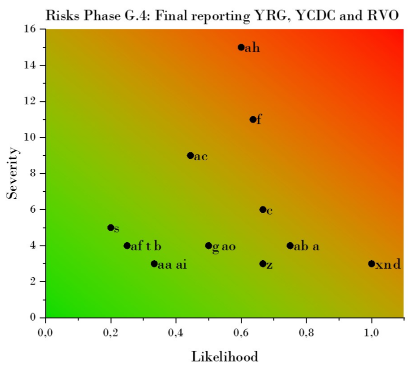
(b) Risk matrix of phase D, where risks *r*, *n*, *an* and *z* are the most crucial



(c) Risk matrix of phase E, where risk *ae*, is the most crucial



(d) Risk matrix of phase F, where risks *am*, *ao* and *an* are the most crucial



(e) Risk matrix of phase G.4, where risk *ah* is the most crucial

Figure 33: Risks of phase C, D, E, F and G.4

F Scenario analysis: values of the activities

F.1 Scenario 1

Table 2: The duration of the activities per time estimation of scenario 1

Phase	**min**$_1$	**min**$_2$	**max**	$\mathbb{E}(\boldsymbol{T})$
B.1.3	99	71	84	81
B.2.1	49	48	106	75
B.2.2	29	28	30	35
B.2.3	67	78	79	80
B.3.1	44	40	64	56
B.3.2	25	33	34	31
B.3.3	45	44	98	62
G.1	274	262	263	261
G.2	139	144	135	130
G.3.1	28	28	47	30
G.3.2	47	33	92	55
G.3.3	99	101	128	118

F.2 Scenario 2

Table 3: New pessimistic duration when risks are prevented

Phase	**min**	**max**	**Total severity**	**Risk f**	**Risk t**	**Risk m**	**Risk w**	**Risk s**	**Risk j**	**Risk a**
B.2.1	27	118 **107**	128	8	-	4	-	4	-	-
B.2.3	34	111 **82**	128	10	6	3	9	4	3	13
B.3.3	21	109 **76**	128	4	3	7	8	3	3	20

Table 4: The duration of the activities per time estimation of scenario 2

Phase	**min**	**max**	$\mathbb{E}(\boldsymbol{T})$
B.1.3	97	80	84
B.2.1	47	92	77
B.2.2	34	46	35
B.2.3	78	67	74
B.3.1	49	67	54
B.3.2	30	29	32
B.3.3	50	59	57
G.1	264	262	261
G.2	117	144	127
G.3.1	20	44	31
G.3.2	61	33	47
G.3.3	95	145	113

F.3 Scenario 3

Table 5: New pessimistic duration when risks are prevented

Phase	**min**	**max**	**Total severity**	**Risk ai**	**Risk af**	**Risk f**	**Risk v**
B.2.1	27	118 **90**	128	-	6	8	26
G.3.1	11	82 **62**	64	3	-	9	6
G.3.3	76	169 **159**	85	5	4	-	-

Table 6: The duration of the activities per time estimation of scenario 3

Phase	**min**	**max**	$\mathbb{E}(\boldsymbol{T})$
B.1.3	51	88	91
B.2.1	51	87	79
B.2.2	29	32	34
B.2.3	73	94	77
B.3.1	43	69	53
B.3.2	32	38	33
B.3.3	47	93	60
G.1	260	262	263
G.2	120	119	126
G.3.1	31	23	31
G.3.2	78	54	44
G.3.3	100	132	112

F.4 Scenario 4

Table 7: New pessimistic duration when risks are prevented

Phase	min	max	Total severity	Risk a	Risk v
B.1.3	25	156 **152**	140	4	-
B.2.1	27	118 **100**	128	-	26
B.2.2	21	63 **57**	119	7	11
B.2.3	34	111 **103**	128	13	-
B.3.1	26	102 **84**	130	4	27
B.3.2	22	57 **55**	112	-	7
B.3.3	21	109 **95**	128	20	-
G.1	216	320 **304**	104	2	14
G.2	81	182 **165**	73	3	9
G.3.1	11	82 **75**	64	-	6
G.3.2	15	112 **96**	66	4	7

Table 8: The duration of the activities per time estimation of scenario 4

Phase	min	max	$\mathbb{E}(\boldsymbol{T})$
B.1.3	99	75	79
B.2.1	49	89	75
B.2.2	30	34	32
B.2.3	83	83	77
B.3.1	39	61	52
B.3.2	26	41	33
B.3.3	39	77	64
G.1	255	249	260
G.2	126	151	125
G.3.1	21	46	36
G.3.2	44	39	45
G.3.3	110	127	114

F.5 Scenario 5

Table 9: New pessimistic duration when risks are prevented

Phase	min	max	Total severity	Risk v	Risk a	Risk am	Risk ai	Risk f	Risk t	Risk n
B.2.1	27	118 **77**	128	26	-	23	-	8	-	-
B.2.2	21	63 **49**	119	11	7	3	4	4	3	7
B.3.1	26	102 **76**	130	27	4	3	-	10	-	-
B.3.2	22	57 **44**	112	7	-	-	11	11	8	6
B.3.3	21	109 **88**	128	-	20	-	-	4	3	3

Table 10: The duration of the activities per time estimation of scenario 5

Phase	$\mathbf{min}_1$	$\mathbf{min}_2$	max	$\mathbb{E}(\boldsymbol{T})$
B.1.3	96	100	113	83
B.2.1	51	40	77	69
B.2.2	27	26	32	33
B.2.3	64	78	85	79
B.3.1	46	51	59	50
B.3.2	26	31	32	31
B.3.3	41	53	74	59
G.1	266	265	276	265
G.2	134	134	115	132
G.3.1	28	30	44	34
G.3.2	18	70	50	51
G.3.3	113	101	143	114