MitC-GERT : An alternate network distribution in mitigation controller

Probabilistic restructuring of complex construction project activity linking using GERT

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TUDelft

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by

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Preface

The inspiration for this tool stems from my bachelor thesis and graduation professor. During my bachelor's, I was introduced to the notion of probabilistic network diagramming and its applications. Although the bachelor thesis was in a different domain, I used the concepts of control and linear optimisation for my graduation thesis. Furthermore, my graduation professor is an expert in the domain of GERT and has published relevant papers and books on the same.

Einstein discovered black holes in his principles of general relativity in the 20th century. However, the first recorded image of the black hole was taken in 2021. This unique feat is owed to the advancement of today's computer processing powers. Similarly, inspired by the story of the first picture of the black hole, another line of reasoning for taking up this development statement was the motivation to repurpose an existing tool with a novel modelling technique. I aimed to find a new meaning for an obsolete methodology in the current age.

This report is written to fulfil the graduation requirements for a Master's in Construction Management and Engineering at the Delft University of Technology. The intended target group for my report is project managers, researchers, and project scheduling software developers. I was involved in developing this thesis from March to August 2022, and during this period, I was hired at Vijverberg as a graduate intern.

Finally, I could not have sustained my progress with the tool without the timely guidance from my supervisors at the university. They have matched my enthusiasm and expectations with the tool's outputs. Additionally, I would like to thank my company supervisors for their unwavering assistance in all the radical thinking and assumptions required to program the tool. I want to express my deepest gratitude to my friends and family for their support throughout my master's at the Delft University of Technology, especially during the pandemic. A special note of appreciation to my friends at Delft for their wise council has always motivated me to carry on.

I sincerely hope you enjoy your reading.

Summary

The purpose of this graduation thesis entitled "Probabilistic restructuring of complex construction project activity linking using GERT: an alternate network distribution in mitigation controller" is to analyse the effect of project network structures when the duration of the project activities is distributed stochastically and its following effect on the existing Mitigation Controller©. The researchers at TU Delft have developed a state-of-art tool called Mitigation Controller© (MitC) for automating the search for finding the most cost-effective set of mitigation measures to ensure the probability of the project's completion at a required level. However, there is a modelling error in the project network diagram of this tool. The risks and uncertainties are modelled using a Program Evaluation and Review Technique (PERT) distribution. The current Mitigation Controller has managed to recreate the human-oriented selection of mitigation measures, but it has not considered all possible scenarios within a complex construction project.

PERT is the most straightforward distribution used for explanatory purposes. This does not reflect real-life conditions. There are instances where certain activities are repeated when the result does not meet the required quality. To overcome the limitations of PERT, it is suggested to implement the Graphical Evaluation and Review Technique (GERT) for scheduling construction projects. A new code is integrated into the existing Mitigation Controller to generate new network paths based on the probabilistic nature of the project activity. The novel network structure is used to compute the optimal set of mitigation measures using Monte Carlo analysis and linear optimisation. It is also observed that the optimisation solver takes a substantial amount of time to compute depending on the number of activities on the project. An efficient Monte Carlo analysis is implemented to reduce optimisation time within the tool. The results created by the simulation tool are (1) project network structure, (2) mitigation measures criticality, (3) project path criticality, (4) project activity criticality, (5) project completion probability distribution (S-curve), and (6) project cost probability distribution.

The report comprises three chapters, each dealing with different aspects of the overall R&D methodology of the tool. Chapter 1 is developing methodology and describes the approach to developing a simulation tool that optimises mitigation measures in a complex construction project based on GERT. Chapter 2 presents the draft scientific paper to be published in a journal. Chapter 3 concentrates on personal reflections resulting from carrying out this graduation thesis.

We have seen conclusive results by validating the MitC-GERT tool with an industrial case study from a Dutch project management company specialising in complex construction projects. The simulation tool generated a higher number of network paths and provided a higher cumulative probability distribution for project completion. It was also observed that the simulation time for the complex project with a high number of activities was minimised while ensuring the high accuracy of probability of completion time. The findings from the validation of this tool include producing a graphical representation of feedback loops within the project. Future work on this topic may include developing the concepts of Queuing-Graphical Evaluation and Evaluation Technique (Q-GERT) into the Mitigation Controller. Q-GERT deals with conditional probabilistic network attribute within a project and specialises in accommodating multiple project teams simultaneously.

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1

Development Methodology

The researchers at TU Delft have developed an innovative simulation tool called 'Mitigation Controller© (MitC)(Kammouh et al., 2021). MitC helps select mitigation measures for a complex construction project by considering all possible scenarios that could occur during the execution of the project. The primary focus of this report is on the scheduling technique used while modelling the project. Current industrial norms implement the use of the Program Evaluation and Review Technique (PERT) in construction risk analysis. This is used to accommodate the pessimistic and optimistic times in a project. The duration of each activity is assumed to be a random variable that follows the Beta distribution in PERT. The primary objective of this report is to study an alternative approach to model construction projects to replicate realistic time delays during the initial stages of the project. Subsequently, the improved construction schedule is used to develop a tool that optimises mitigation measures. The risks and uncertainties are modelled using the Graphical Evaluation and Review Technique (GERT). This technique could address the shortcomings of the existing tool by addressing multiple branching, probabilistic branching, and repeating activities via feedback loops in a project network model (Mubarak, 2019). GERT also adapts deterministic/probabilistic start and end times for activities. Based on this model, we can run a Monte Carlo Simulation and a weighted multi-objective linear optimisation to arrive at the set of mitigation measures.

Development Gap

PERT is a scheduling strategy created to plan a construction project and portray the tasks required in completing a specific project utilising a network of related and comparable activities while coordinating optimal cost and time requirements. The Mitigation Controller uses Beta-PERT to define project network attributes like activity duration, risk, and mitigation measures. Even though PERT is an excellent tool for predicting event durations, there are certain limitations to this approach:

- All activities must be completed in order for the project to be completed (branching from a node is "deterministic" - it must take place).
- All activities leading to an event must be completed before the event can be realised.
- There is no looping allowed; that is, no event may be repeated.
- The distribution of activity times is limited to the beta distribution for PERT.
- Only one terminal event (sink node) represents the project's completion.

Development Statement

The Mitigation Controller© is developed to simulate the human goal-oriented optimisation required to select the optimal set of mitigation measures to ensure timely project completion using the PERT distribution for project activity duration, risks, and mitigation duration. This distribution is deterministic and less efficient when the number of project activities is increased for analysis. It would consider alternative scenarios within a project as an additional mitigation measure. However, The MitC-GERT enables the simulation tool to account for probabilistic branching and repeating activities in a project network. This novel distribution replicates the real-life development of incorporating multiple scenarios within the initial project network analysis by modelling rework and choosing different paths in a project.

Need Analysis

The need-analysis is performed via literature review, reports, and case studies. It is observed that one-third of construction projects overran their budget. Researchers have merged fuzzy logic with PERT to improve schedule control outcomes (Chanas & Zieliński, 2001; Buckley, 1988; Chanas et al., 2002; Chanas & Kamburowski, 1981; Shipley et al., 1997). As the computers advanced, Monte Carlo Simulations became prevalent in calculating complex uncertainties. Monte Carlo simulation is an excellent method for resolving uncertain problems, particularly construction schedule management. Table 1 encapsulates the current and desired state of the objectives charted out for this research.

Table 1 Need Analysis

Objective	**Current State**	**Desired State**	**Development Gap**	**Remedies**
Simulate real-life projects by incorporating multiple scenarios in the initial analysis	Fixed project network and probabilistic risk and uncertainties modelling	Probabilistic project network, risk, and uncertainty modelling	The transition from deterministic to probabilistic network linking	Implement GERT instead of PERT (Pregina & Kannan, 2022)
Increase efficiency in running the optimisation simulation	Search time for an optimal value within the optimisation solver increases with the number of activities modelled in the project	Rapid search for an optimal value without comprising the accuracy of the simulation result	Lack of predictive analysis within each cycle of Monte Carlo analysis	Implement an efficient method of running a Monte Carlo analysis for GERT distributed projects (Kurihara & Nishiuchi, 2002)

The current Mitigation Controller can not incorporate double or multiple scenarios within the project network. The current MitC would consider the second scenario as a new kind of mitigation but using GERT is one of the possible paths in the project. GERT is not binary decision-making and is not computed in a zero-one assessment regarding certain activities. This reflects the real-life conditions that exist in complex construction projects. Furthermore, The current MitC calculation is slow and is not an efficient tool for extensive schedules with many line items.

Formulation of relevant design requirements

To overcome the limitations of PERT, the author suggests the implementation of the Graphical Evaluation and Review Technique (GERT) for scheduling construction projects. PERT follows a deterministic node branching as depicted in Figure 1. All activities emanating from the node are realised in this case. GERT follows a probabilistic branching, as shown in Figure 2. In this case, one branch is realised at any time. The sum of all activities emanating from a probabilistic node should be 100%.

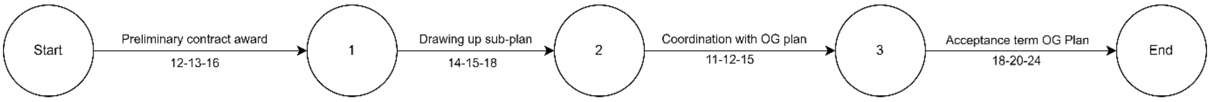


Figure 1 Deterministic node branding in PERT

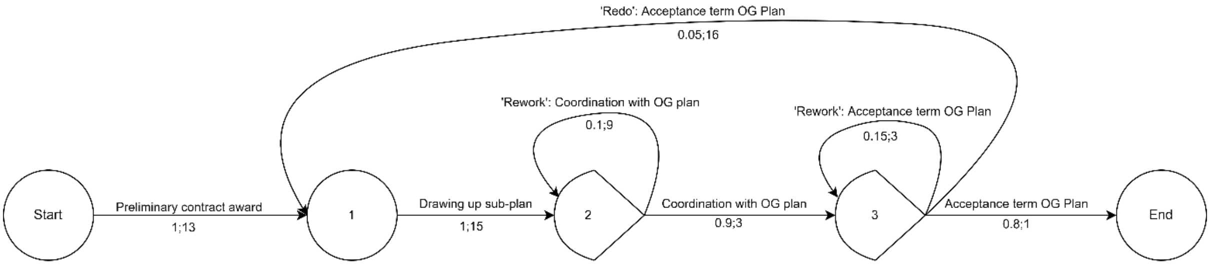


Figure 2 Probabilistic branching in GERT

There are certain features of GERT which are not available in PERT, such as probabilistic branching (stochastic networks), network Looping (feedbacks loops), network modification during execution (learning capability), multiple sink nodes (multiple project outcomes), specified activity releases (activity completions to realise a node may be less than, equal to, or greater than the number of activities terminating at a node), multiple probability distributions (nine different probability distributions may be associated with activity parameters), multiple types of node input (four types of logic may be related to node realisation), multiple types of time statistics collection (five different types of time statistics may be collected at network nodes), statistics on the probability of node realisation (probability of realising various outcomes). The time distribution for project activity duration in PERT and GERT is assumed based on the type of rework/redo carried out with the activity. This assumption is illustrated using an example of the submission of steel drawings for approval in Table 2.

Table 2 Time distribution assumption in PERT and GERT

Distribution Type	**Activity Type**	**Time Duration**
PERT	Shop drawings steel, including updated ICF	T = 78 Days
Total time duration = T = 78 Days		
GERT	Shop drawings steel, including updated ICF	X= 34 Days
	Rework: Shop drawings steel, including updated ICF	Y = 10 Days
Total time duration = 2X+Y = 78 Days		

Development Modelling

The development of the tool is primarily split into two phases: modelling the project network and optimising mitigation measures. We aimed to transform the existing projects into a GERT distribution in the first phase. To achieve this, it is essential to understand the project's processes and project activity flow. Subsequently, with the improved project network, the second phase aims to run an optimisation within each Monte Carlo Simulation in the mitigation controller. The verification and validation of the simulation tool are conducted through post-mortem analysis of an ongoing construction project. The data for the second phase is based on the open-source code available in the GitHub repository as part of the Green Open Access initiative in The Netherlands. The complete development modelling is depicted in Figure 3, and the program structure diagram of MitC-GERT is given in Figure 4.

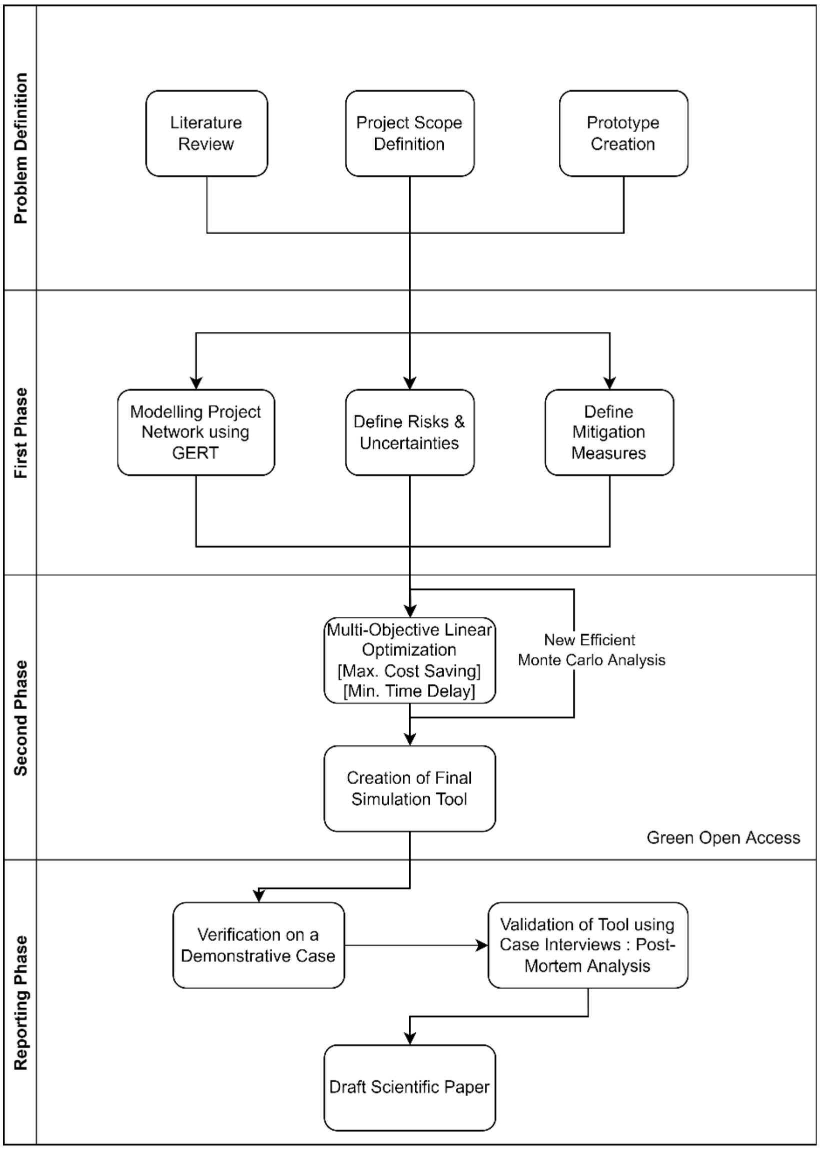


Figure 3 Development modelling

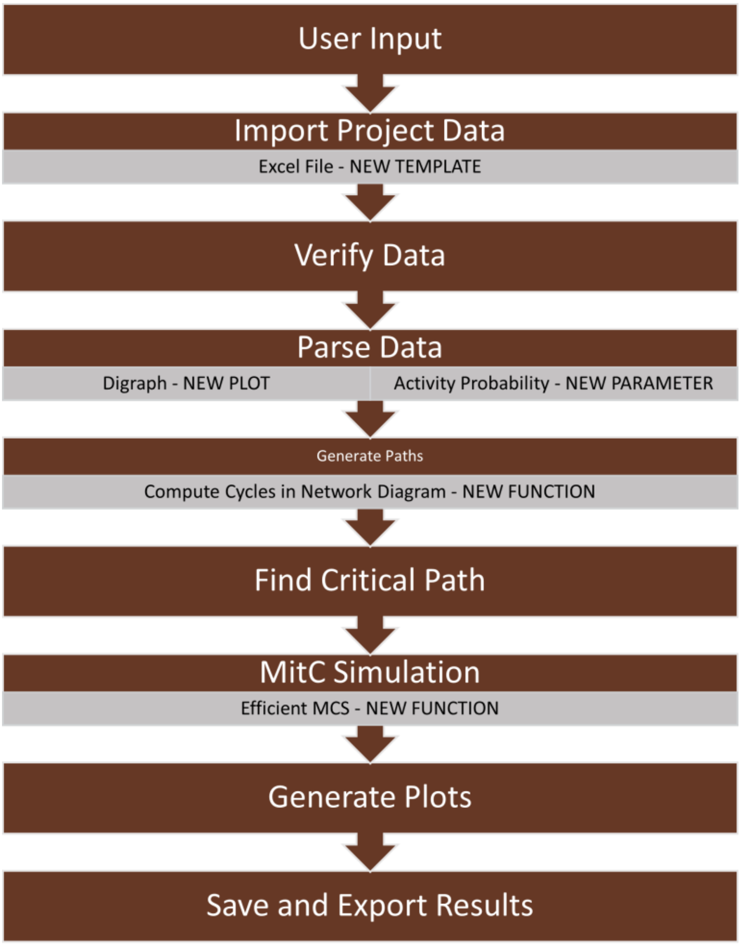


Figure 4 Program structure diagram of MitC-GERT

Verification of simulation tool on a demonstrative case study

The final product was tested on an ongoing complex construction project in the Netherlands. The project was renovating a bridge deck on the Haringvliet water inlet. Since the bridge was still operational, a detailed project management plan was required to schedule a closure for the renovation. Several constraints were associated with the project, and the renovation was to be completed within a stipulated period as they have a scheduled road and maritime traffic closure period. Due to the constraints, the project is classified as complex. With the assistance of the project manager involved in the project, we were able to identify four point-of-no-returns. These checkpoints were crucial to understanding the progress of the project.

To study the effects of the alternative distribution type, we have ensured that the risks and mitigation measures were the same in both analyses. The exhaustive inventory of risks and mitigation measures are given in Appendix C and Appendix D, respectively. Furthermore, we identified several activities that generally required reworks. A complete list of activities used for analysis is given in Appendix A and Appendix B. The results generated by the MitC-GERT are given in Figure 5.

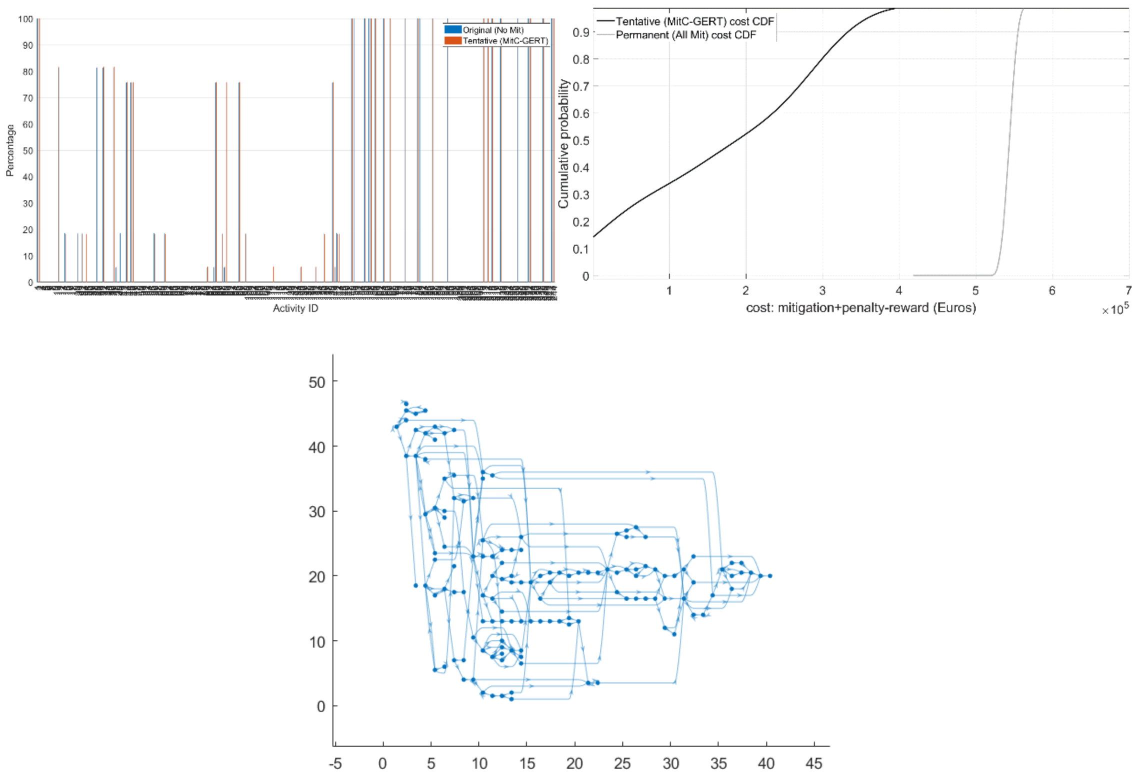
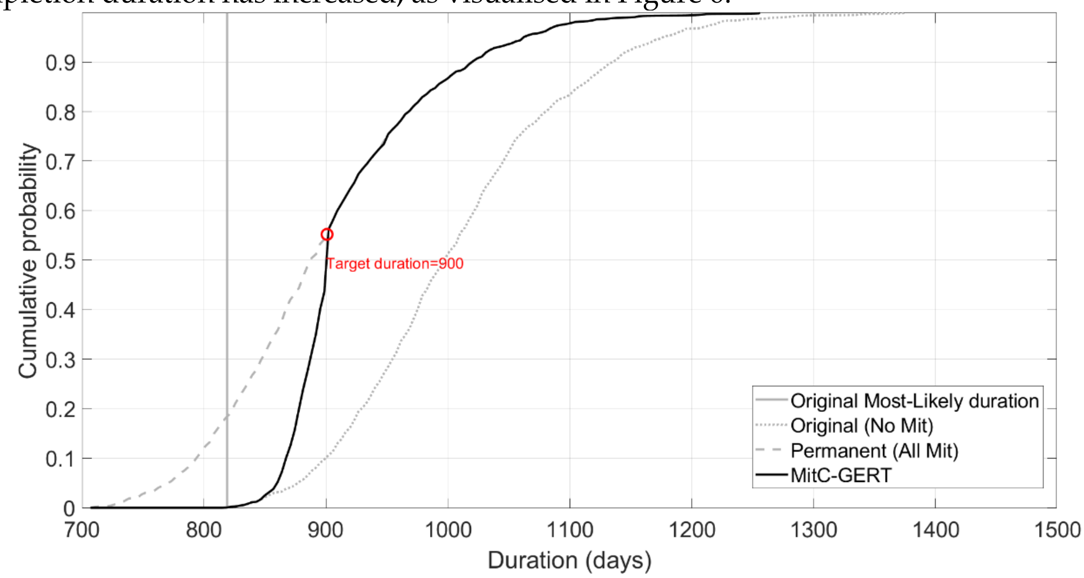


Figure 5 Activity Criticality Index (Top-Left), CDF of Cost (Top-Right), and Project Network Diagram (Bottom)

Validation of simulation tool

The validation of the MitC-GERT was conducted using post-mortem analysis employing case interviews with the project manager involved in the renovation project. During the preliminary interview, we could identify the crucial activities that could require potential reworks. After running the simulation, we concluded that the overall range of the project completion duration has increased, as visualised in Figure 6.



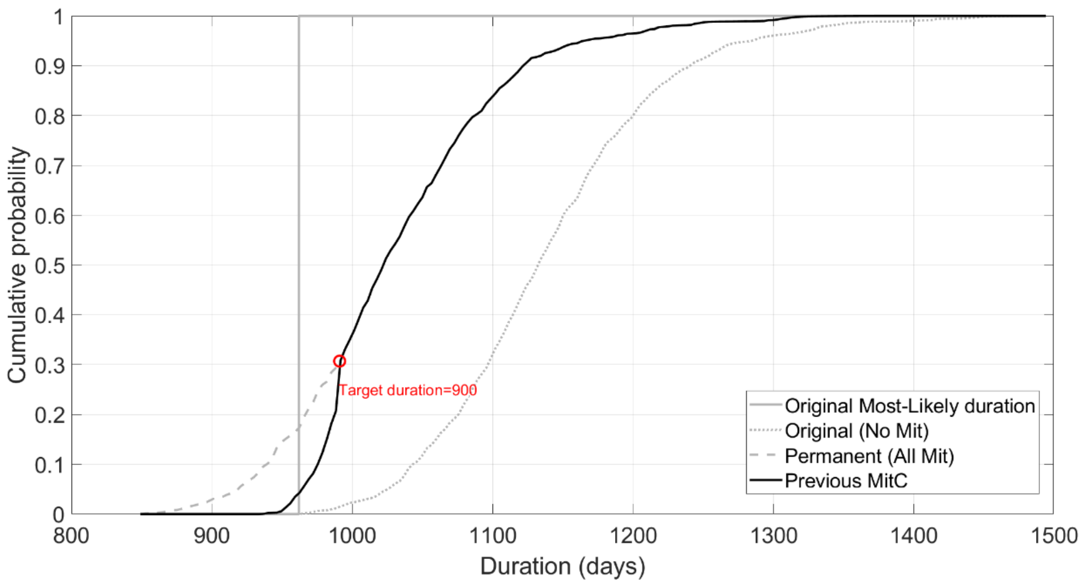


Figure 6 CDF of project completion: MitC-GERT (Top), MitC (Below)

Furthermore, we also noticed that the cumulative probability of completion increased when we implemented GERT as the modelling technique. The efficiency increase is an added value for construction project managers and analysts when studying the paths before the project's commencement. The accuracy of the simulation is depicted in Figure 7, which is accounted for by the use of the new efficient Monte Carlo analysis.

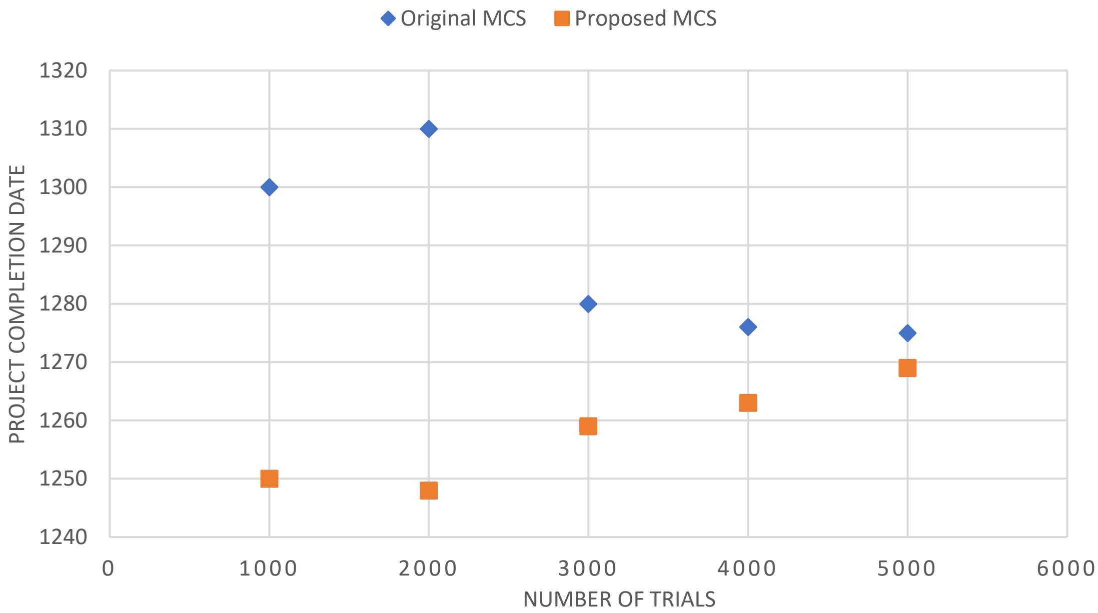


Figure 7 Simulation results with the original and proposed Monte Carlo Simulation

A case interview was conducted with the project manager responsible for the demonstrative example to analyse the effect before and after implementing the MitC-GERT. The findings are outlined in Table 3. The case demonstrator was tasked with developing a proper planning and risk analysis for procuring the tender from the government. After validating the MitC-GERT on the project, specific outcomes were drawn and are mentioned in Table 3.

Table 3 Summary of the Post-Mortem Analysis

Attribute	Conventional Analysis	Post-'MitC-GERT' analysis
Number of project paths	105982 paths were analysed.	489435 paths were analysed. This includes 'reworks' and 'redos'.
Identification of mitigation measures and potential project paths	Implementation of a backup team for the new bridge deck's lifting phase was initially considered a mitigation measure.	We observed a high probability of requiring a backup team through the analysis. One line of reasoning is that a higher probability of occurrence was given to this activity due to the prevalence of Corona. If a particular team member was affected, the entire team was quarantined. Therefore, the management decided to implement this as a potential project path and not a mitigation measure.
Introducing two probabilities of occurrence to each activity; Soft constraints and hard constraints	The conventional analysis does not have a probability of occurrence.	The soft constraints are based on the project manager's intuition and experience, whereas the hard constraints are based on the project system requirements, scientific guidelines, and engineering skills. For instance, the project manager noticed that the success ratio of crossing the first point-of-no-return (maritime traffic obstruction) was very low. Therefore, the upper management decided to employ extra sub-contractors to ensure additional Critical Design Reviews (CDR).
Supplementary benefit during Tender Application (Most Economically Advantageous Tender, EMVI)	A specific factor in the tender application was the 'robustness of the planning'. Using the conventional analysis, they could score a rating of '7' (sufficient added value).	With the help of MitC-GERT, their planning was bolstered with additional paths and comprehensive analysis. They could apply with a rating of '8' for the 'robustness of the planning' factor. In return, they receive a more significant discount in their final bid and stand a better chance of getting the tender contract award.

The MitC-GERT is operationally relevant, and its originality to the construction industry are the following reasons: (1) It is quick and easy to use for non-specialists. It has enough details to start further analysis for Project Managers (2) Research in more advanced technologies like Artificial Intelligence for predictive modelling in the construction industry is becoming more prevalent, (3) Project network loops are highlighted within the analysis, (4) Possibility of including different scenarios in the initial project planning phase, and (5) two new KPIs for the construction industry because of the new parameter of Probability of occurrence of activity within a project.

GERT has not gained traction to the best of the author's knowledge in the construction industry. In reality, it has sparked limited attention in the academic field. This tool remedies the manual trial-and-error of running different scenarios by drafting a new project plan for each case by accommodating all known project paths in its analysis. With the help of this tool, a project manager could avoid choosing a path that leads to multiple iterations later in the project.

2

Draft Scientific Paper

This chapter presents the manuscript for publishing the workings of the MitC-GERT as a draft scientific paper. The following pages in this chapter also serve as a stand-alone document.

Probabilistic restructuring of complex construction project activity linking using GERT: an alternate network distribution in mitigation controller

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Abstract

The Mitigation Controller© (MitC) has successfully implemented an optimisation degree to the mitigation measures in complex construction project. This tool has mainly focussed on maximising profits and minimising the delays in a specified project. Furthermore, this tool has strived to achieve a human-goal oriented approach in optimising the set of mitigation measures. However, this tool is modelled on a simplistic and deterministic project network. The project activities are assumed to be realised in a linear approach. This method of modelling does not reflect the real-life progression of project activities. There are instances where a project is delayed because of rework and conditional prerequisites. Such features are not explicitly demonstrated when modelling the current industrial planning tools. Additionally, it was observed the the MitC was less efficient when the project had larger number of activities. The MitC-GERT focuses on implementing an alternative project network linking to tackle the shortcomings of the existing MitC. The risks and uncertainties are modelled using the Graphical Evaluation and Review Technique (GERT) and incorporates an efficient Monte Carlo method to increase the efficiency in optimisation of the tool. The validation concludes that the cumulative probability of completion increased and the simulation time has been optimised. The MitC-GERT also provides valuable insight on the activities that require reworks and feedback loops. The MitC-GERT is developed using an open-source code written in MATLAB® language and a graphical user interface (GUI) for ease-of-use.

Keywords: GERT, Monte Carlo Simulation, Multiple Branching, Probabilistic Branching, Mixed Integer Linear Optimization

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1. Motivation and significance

A project schedule is a graphical representation of the chronological sequence of the project activities involved in a project[1]. The number of activities and their diversity defines whether a project is complex. The uncertainties in a construction project stem from the project's unique aspects[2]. Due to these uncertainties and risks, a complex construction project will likely get delayed. A project manager cannot handle these critical risks solely in the interest of project schedules and budget complications, nor can a project manager assume the factors are affected equally[1]. Therefore, a quantitative risk analysis is paramount before starting a construction project[3]. Accordingly, companies in the construction industry have been forced to implement advanced risk analysis to stay in a competitive market[4]. The planning department and the risk analysis team within a construction company are tasked with developing mitigation measures to prevent the risks from taking place. These mitigation measures can be drawn from past project experience, extensive case research, and scientific literature[5].

The researchers at Delft University of Technology have developed a state-of-art tool called Mitigation Controller© (MitC)[6] for automating the search for finding the most cost-effective set of mitigation measures to ensure the probability of the project's completion at a required level. However, there is a modelling error in the project network diagram of this tool. The risks and uncertainties are modelled using a Program Evaluation and Review Technique (PERT) distribution. Current industrial norms implement the PERT in construction risk analysis[7]. It is used to accommodate the pessimistic and optimistic times in a project. The duration of each activity is assumed to be a random variable that follows the Beta distribution[8]. Even though PERT is an excellent tool for predicting event durations, this approach has certain limitations. For instance, it focuses on a single (or deterministic) path during the execution of the project. Project managers practice rescheduling (adjusting and correcting) tasks based on the current project scenario. PERT does not account for such human behaviour[9].

To overcome the limitations of PERT, the author suggests the implementation of the Graphical Evaluation and Review Technique (GERT) for scheduling construction projects. This paper introduces the Mitigation Controller-GERT (MitC-GERT) software tool as a novel solution that aids in modelling risks and uncertainties in complex construction projects using the GERT. This technique could address the shortcomings of the existing tool by addressing multiple branching, probabilistic branching, and repeating activities via feedback loops in a project network model[10]. GERT also adapts deterministic/probabilistic start and end times for activities[9]. Based on this model, we can run a Monte Carlo Simulation and a weighted multi-objective linear optimisation to arrive at the set of mitigation measures.

The practitioners in the construction industry prefer to use a stand-alone application compared to a complex code environment. The software MitC-GERT is written in MATLAB® language and is launched using a Graphical User Interface(GUI) developed using the App Designer in MATLAB®. The GUI was designed with the intent of ease of use. Hence, project managers with limited computer programming knowledge can utilise the software. This software is an extension of the Mitigation Controller mentioned in [6]. This paper concentrates on the application of the tool and not the scientific background. A detailed description of the algorithm and theoretical background for the software can be found in the repository[11]. GERT has not gained traction to the best of the author's knowledge in the construction industry. In reality, it has sparked limited attention in the academic field[9]. Hence, The authors believe that the tool is a forerunner in the construction industry to consider scheduling projects using alternative techniques.

2. Software description

2.1. MitC-GERT objective and consideration

The MitC-GERT accounts for the occurrence of activities in a project path. The primary objective of this software tool is to model construction project schedules in a stochastic manner that considers unplanned reworks, iterations, and alternate measures during the execution phase. Another objective is to increase the efficiency of the current version of the mitigation controller mentioned in [11]. To accomplish these objectives, the author implements the use of GERT in project planning analysis as it resolves the variability associated with these projects. Several attributes were considered while framing the input characteristics for this tool. The summary of these attributes is given in Table 1. Project managers are this tool's primary users as it helps select an optimised strategy during construction. Project managers assign the probability associated with the activity based on the management plan, workforce, and engineering skills. Hence, these practitioners evaluate the validity of the input data before feeding it to the simulation engine. The outline of the input file is illustrated in Fig. 1. The data comprises (a) a description of the activities with the probability of occurrence and their associated activity duration,(b) a set of mitigation measures with its capacity to reduce the project duration and its connection to the project activities, (c) a set of risks involved in the project with their probability of occurrence and its delay caused on the project activity, and (d) a description of the correlation between project activities that share the same risks and uncertainties.

Table 1: Summary of the attributes used in MitC-GERT

Attribute	Description
Classification of Activity Types	The activities are categorised based on their iterative nature in the project. Certain activities are deterministic and obligatory in the succession of a project path. On the other hand, other activities call for rework if it does not satisfy the desired outcome. The activities that require going back in a project path are labelled with the tags: 'Redo' and 'Rework'. A 'Redo' activity is when circumstances require a project manager to carry out the same activity as it has not achieved its intended result. In the project path, this accounts for self-looping as it runs the same activity for multiple iterations. A 'Rework'activity is when a project manager is required to reevaluate the entire process leading up to the given activity. A detailed explanation of the categorisation is given in [12].
Risk probability and its effect on the project	A comprehensive risk analysis is conducted to identify the possible delays in a project. Depending on the complexity and familiarity of the project, a certain probability of occurrence is given to each risk event. The proper identification of risks directly correlates with the project's delay, and it further helps in the appropriate analysis of its time and cost overruns.
Uncertainty in activities, risks, and mitigation capacity	The data set required for Monte Carlo sampling is taken from considering a beta distribution of uncertainty. A project manager assesses a three-point estimate for this uncertainty based on the activity. The valuation of this uncertainty is vital for modelling the optimisation, as it defines the scope of the simulation[13].
Interdependencies of activities	The relation between activities, risks, and mitigation measures is defined with this attribute. It instructs the compiler to follow a specific project path based on input. Additionally, a project manager can define if there are shared uncertainties between activities.
Costs associated with each mitigation measure	Each mitigation measure financially affects the project based on its scale and resources. The cost-benefit of each mitigation is one of the optimising parameters of MitC-GERT. The range of the mitigation measure is defined using a formula mentioned in [6].
Economical benefits based on early and late finish	Projects incur high costs in the event of a delay, and at the same time, they gain profit if they finish early. The project manager assigns a reasonable daily fixed cost and incorporates it into the simulation. This leads to selecting the project with the best overall cost.

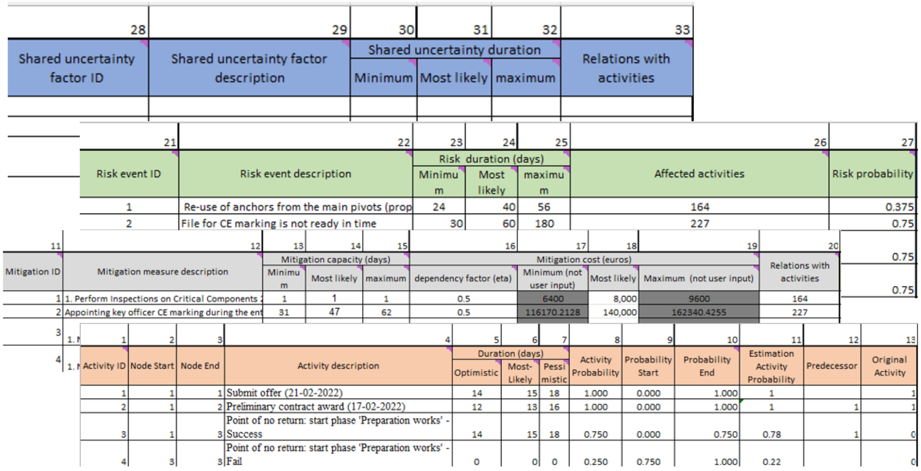
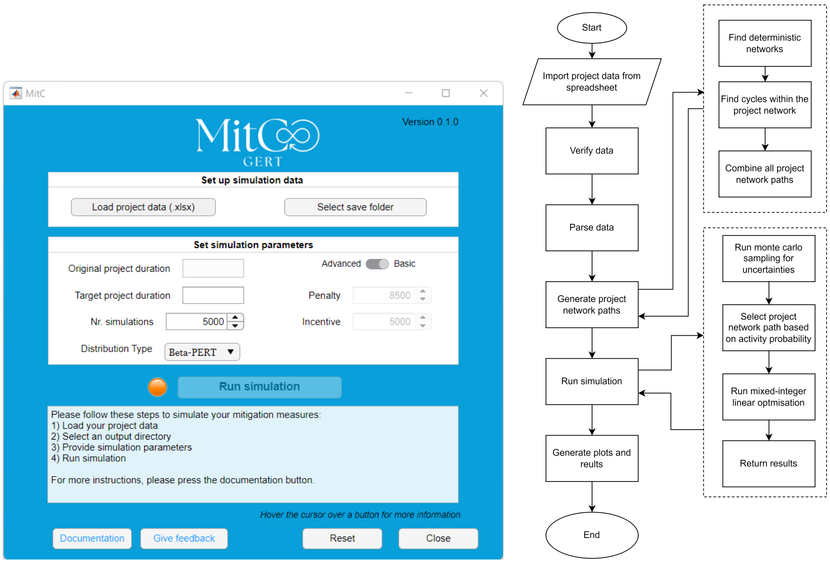


Figure 1: example of input spreadsheet template

2.2. Software Architecture

The input data for the MitC-GERT is detailed in Figure 1. The user has to be responsible for verifying the input value's fitting. A predefined spreadsheet template is provided along with the software as an aid to feed in the required data. The graphical user interface (GUI) is shown in Figure 2-a. The GUI was designed using the App Designer function of MATLAB®. Simplicity and readability were the main factors that inspired this design as a GUI. The different components of the MitC-GERT are detailed in Table 2.

The entire workflow of the MitC-GERT is illustrated in the flowchart in Figure 2-b. The mitigation controller considers the type of distribution specified in the input parameters and starts analysing the project network path. After generating the number of project paths, it examines the risk events and mitigation measures to check their influence on the project network. The verification of the input data is also carried out at the beginning of the workflow to inform the user of any data errors. After finding the initial critical paths and conducting the preliminary checks, the tool enters a simulation where it conducts a Monte Carlo sampling by assigning random samples from the given input data for the duration of project activity, risks, and mitigation capacity. The project completion duration is calculated at each iteration, and if the tool computes a delay in the project, it employs mitigation measures to achieve the desired target duration. The MitC-GERT then records the mitigation measures used in each iteration, while optimisation is based on the costs of the mitigation measure, penalty charges for the days delayed, and a reward for the project's early completion. The outputs generated by the tool are discussed in the following sub-section.



(a) Graphical User Interface (GUI) (b) Software architecture

Figure 2: Front end devlopment of the MitC-GERT

Table 2: Components of the MitC-GERT GUI

Type of Component	Component	Description
Parameters	Number of simulations	Set the total number of iterations to be executed for Monte Carlo sampling.
	Target duration	Set the desired project completion duration.
	Penalty	Assign a daily cost for the delay in a project.
	Reward	Assign a daily incentive for an early competition of the project.
	Distribution Type	Assign the type of distribution to be considered for activity, risks, and mitigation measures. [Beta-PERT, GERT]
Functional Buttons	Switch	Adjust between the basic and advanced modes in the tool. The penalty and incentives are coded in the advanced mode.

	Load Project Data	Loads the input spreadsheet into the tool from the user's system.
	Select Save Folder	Creates a new folder in the user's system to store the results and plots generated from the folder.
	Run Simulation	Initiates the simulation and disables the input features of the tool.
	Documentation	Redirects to the tool's documentation on GitHub.
	Give Feedback	Redirects to a feedback form to the developers of this tool.
	Reset	Deletes the input parameters and resets the tool.
	Close	Terminates and shutdowns the tool.
Logging	Message Window	Conveys errors, warnings, and progress of the tool.
	Indicator Light	Indicates the current setup of the tool. Orange: Requires input. Red: The tool encountered an error. Green: The tool is ready to run the simulation.

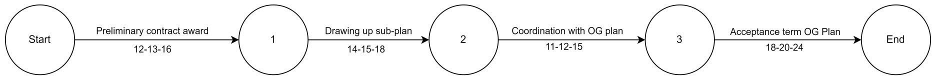
2.3. Software Functionalities

The MitC-GERT follows mixed-integer linear programming (MILP) to locate the optimal set of mitigation measures. The tool ensures corrective actions at each iteration to achieve the desired project completion duration in the Monte Carlo simulation. The optimisation technique used in MitC-GERT is based on the original mitigation controller. The mathematical design behind the optimisation is detailed in [6]. For further clarification on this function, refer the documentation [11].

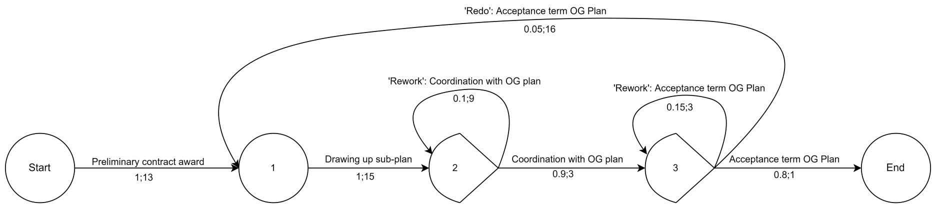
Additionally, the current version of the mitigation controller engages in analysing a project using a different distribution type. Implementing the graphical evaluation and review technique (GERT) helps iteratively model the project paths according to their probability of occurrence. Figure 3 shows the graphical representation of the execution of a project activity using PERT and GERT. In the first case, PERT assigns a stochastic distribution to the project activity attribute and follows a linear succession in the project network structure (Figure 3-a). In the second case, GERT follows the same stochastic distribution for project activity attributes and network structure. In this case, a probability of occurrence dictates the progression of the following activity within its network structure (Figure 3-b). The simulation calculates various project paths depending on the random probability. An example of the classification of an activity based on its distribution type and its changes in the input is shown in Table 3. The results generated by the MitC-GERT is a report of the optimal set of mitigation measures to be considered while achieving the required completed project duration. Other project results include (1) a project network diagram, (2) mitigation measure criticality, (3) project path criticality, (4) project activity criticality, (5) project completion probability distribution (S-Curve), and (6) project cost probability distribution.

Table 3: Classification of activity based on its distribution type and input

Dist. type	Activity ID	Node start	Node end	Activity description	Optimistic time	Most-likely time	Pessimistic time	Activity probability	Predecessor activities
PERT	1	Start	1	Preliminary contract award	12	13	16	1	
	2	1	2	Drawing up sub-plan	14	15	18	1	1
	3	2	3	Coordination with OG plan	11	12	15	1	2
	4	3	End	Acceptance term OG plan	18	20	24	1	3
GERT	1	Start	1	Preliminary contract award		13		1	
	2	1	2	Drawing up sub-plan		15		1	1
	3	2	2	'Rework': coordination with OG plan		9		0.1	2
	4	2	3	Coordination with OG plan		3		0.9	2
	5	3	3	'Rework': acceptance term OG plan		3		0.15	4
	6	3	1	'Redo': acceptance term OG plan		16		0.05	4
	7	3	End	Acceptance term OG plan		1		0.8	4



(a) PERT



(b) GERT

Figure 3: Project network diagram of accepting an OG plan

3. Illustrative Examples

This section outlines the processes of the MitC-GERT using real-time data of an ongoing complex construction project. The main results and outputs are documented, and further information on running the tool can be found in the repository.

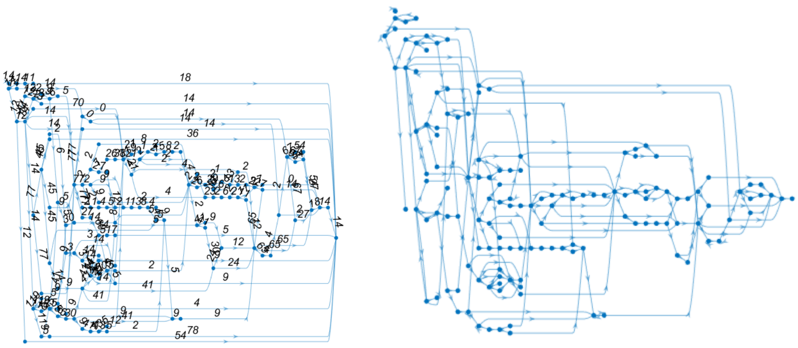
Using this example, the authors wish to define the differences between the current industrial scheduling techniques and their alternatives. The project used in this analysis is a renovation of a bridge deck in the Netherlands. After consulting with the project's sub-contractor in charge of planning and risk analysis, 138 scheduled activities are considered for this analysis. The selection criteria for these 138 activities were based on their criticality and complexity in the project. The number of activities could not be further reduced because it compromises the level of detail required while seeking government approvals. Hence, the authors aimed to attain industrial relevancy and not remain in the realms of theoretical concepts. The initial project duration is calculated to be 961 days when the project is modelled using PERT. This is the project's duration when no risk and delays have occurred during the project's execution. The tool calculates this target duration by analysing the initial critical path of the project. This critical path is not fixed for the rest of the analysis as the simulation considers the various risks and mitigation measures. The input spreadsheet has 33 independent risk events and 33 corresponding mitigation measures in this example. We analyse the project using two cases, each with a different distribution type, PERT and GERT. The input data differs for the GERT distribution because it changes the activity duration depending on the type of activity. There are 244 activities specified in the GERT spreadsheet. The initial target duration in this distribution is calculated to be 816 days. The additional activities include 'rework' and 'redo' activities. Other functional differences in these two cases are discussed in the following subsections.

3.1. Project network structure

The project network structure for the PERT case is illustrated in Figure 4-a. This is the first output from the simulation, and it identifies the initial critical path and calculates the initial target duration. Then it proceeds to map the interdependent activities based on the predefined predecessor activities in the input spreadsheet. This project network is linear and deterministic as the succession of activities is established in advance.

The project network structure for the GERT case is illustrated in Figure 4-b. There is a significant change in the network structure as the tool identifies the interdependencies within activities based on the stochastic nature of the activity. The classification of the activities determines the probability of occurrence in this model.The reason for a shorter target duration is the crashing of activity duration within the model. The current industry practice is to assign a favourable duration to an activity which has a large buffer implicitly. However, by modelling in GERT, the activity duration is split into the required duration and the buffer time. The simulation tool detects loops and cycles within the model because it is a function of GERT to branch based on the activity probability.

Based on the project network structure, the MitC-GERT generates all possible critical paths by running a Monte Carlo sampling of different activity duration, risks, and mitigation measures. The number of paths generated is discussed in the following subsections.

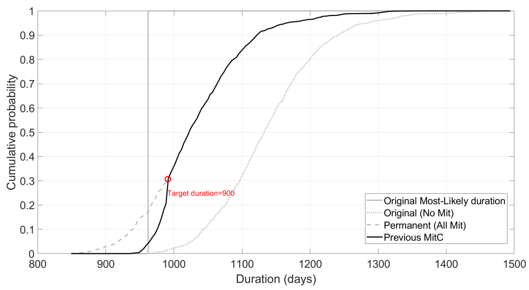


(a) PERT (b) GERT

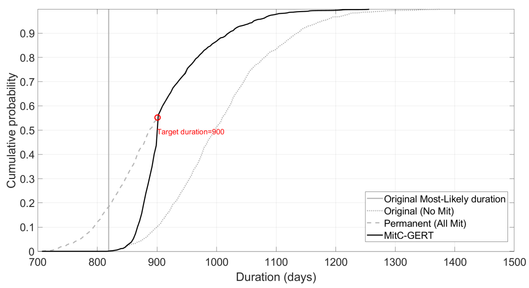
Figure 4: Network structure of the bridge deck renovation project

3.2. Project completion probability duration

The cumulative probability distribution of the project completion is illustrated in Figure 5. The MitC-GERT computes the S-curve in bold solid lines by minimising the time by implementing the mitigation measures based on the risks developed in the Monte Carlo Simulation. The optimisation model ensures that no mitigation overdesign and cost overrun take place. The figures show the S-curve for various scenarios. The initial target duration is highlighted using a vertical line. The S-curve is shown using the light dashed line when all mitigation measures are implemented. Similarly, the S-curve is shown using the light dotted line when no mitigation measures are implemented. The cumulative distribution probability for the PERT case is given in Figure 5-a and for the GERT case in Figure 5-b. We notice a difference in the S-curves generated using these distributions because by implementing GERT, the range of the project duration changes, producing a higher probability of project completion for the same target duration.



(a) PERT



(b) GERT

Figure 5: Project completion probability (S-Curve) of the bridge deck renovation project

3.3. Summary of the simulation

The MitC-GERT generates different results after running the simulation for specified iterations. The mitigation controller's primary result is the optimal set of mitigation measures. The best collection of corrective measures is produced after optimising the project network based on the mitigation cost, rewards and penalties. The objective of the original mitigation controller was to optimise based on the stochastic nature of project activity attributes. The modified MitC-GERT implements a stochastic project network into the optimisation model. The number of network paths and simulation time for PERT and GERT distribution is given in Figure 6. In the example of the bridge deck renovation project, we noticed that the number of network paths generated nearly quadrupled when modelled using GERT. These paths are overlooked when industries conduct a classical Monte Carlo Simulation. The probability of entering one of these paths is limited, but it significantly impacts the project's delay. Furthermore, The simulation time for PERT distribution was nearly 2 hours, and for GERT distribution, it was 6.5 hours. The simulation time increased because of the heavy computational resources required to analyse the 490,345 network paths.

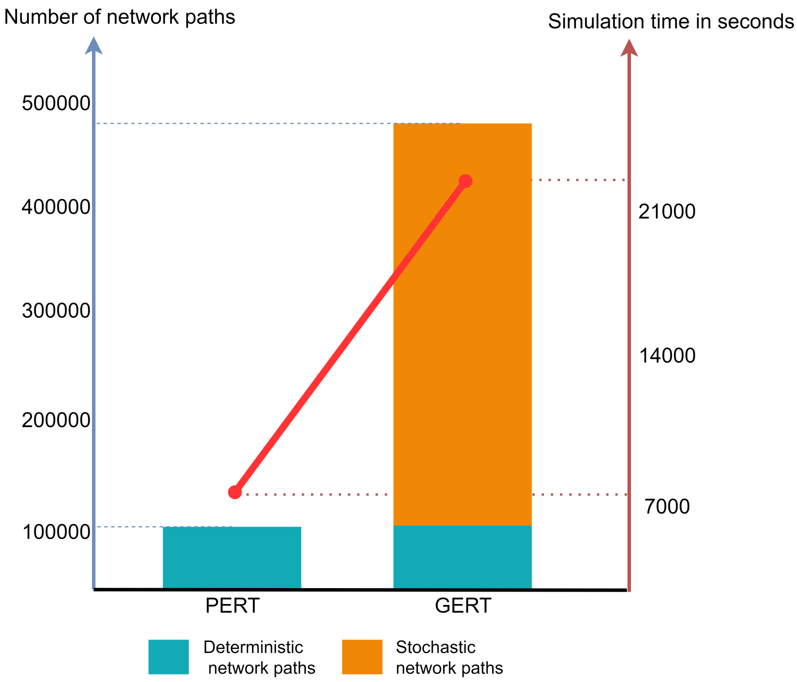


Figure 6: Summary of simulation on the bridge deck renovation project

4. Impact

A case interview was conducted with the project manager responsible for the demonstrative example to analyse the effect before and after implementing the MitC-GERT. The case demonstrator were tasked with coming up with a proper planning and risk analysis for procuring the tender from the government. After validating the MitC-GERT on the project, certain outcomes were drawn: (1) Increase in the number of project paths, (2) Identification of mitigation measures and potential project paths, (3) Introducing two probabilities of occurrence to each activity; Soft constraints and hard constraints, and (4) Aids in bolstering Tender Application (Most Economically Advantageous Tender, EMVI).

The simulation tool has a learning capability that understands modifications in a network during execution. The tool learns from the input data that contains stochastic linking between projects. The analysis can also determine project failure probability because it has multiple end nodes. The project completion probability distribution (S-curves) and the cost distribution probability are valuable assessments that can aid in producing a robust risk analysis report. A project manager can bolster his risk analysis report with the help of the plots generated from the MitC-GERT. A company can gain by implementing MitC-GERT during their tender process for securing the project by claiming additional state-of-the-art analysis that can guarantee the timely completion of complex construction projects.

The MitC-GERT intends to be used in academic research and industrial applications. The concepts of GERT have not been implemented in the construction industry, and this tool aims to be a novel scheduling technique for optimising mitigation measures in a project. The practitioners of the construction industry are reluctant to utilise a mathematical program if it requires them to code manually. Hence, the delivery of the simulation tool is neatly packaged in a user-friendly, intuitive GUI. The GUI has clear instructions to help project managers set up the simulation. This tool does not eliminate the use of human intervention but supports the project manager in making an informed decision based on the simulation results.

5. Conclusions

The construction industry is not at par with other industries (like financial, healthcare, and aeronautical) regarding predictive modelling. The industry's future lies in optimising construction projects and simulating a near-realistic project timeline. One of the fundamental modelling errors in the construction industry is that the project network structures are linear and not stochastic. The authors tried to achieve a real-time simulation of the construction project by using an alternative distribution type for uncertainties in a project called GERT. The authors could modify the project network by implementing GERT with iterations and feedback loops.

This paper introduces a novel simulation tool called the mitigation controller-GERT (MitC-GERT) to address the shortcomings of the existing modelling errors in the previous version of the mitigation controller. The tool enters a simulation where it runs a Monte Carlo sampling to determine the project completion duration while implementing an optimisation program where it searches for the most cost-effective mitigation measured with the least delays and early completion. Moreover, it considers the penalty and reward in the optimisation model. The functions and input parameters used by the simulation tool were detailed in the software architecture subsections, and the code in delivered using an intuitive GUI.

This paper uses a Dutch construction project as a case study for demonstrating the MitC-GERT. In this demonstration, we conduct two analyses on its distribution type, PERT and GERT. The number of risks and mitigation measures were the same, but the number of activities differed due to the classification of the activity. 'Rework'and 'Redo' activities split up the conventional scheduling technique by assuming the project calls for iterations based on its quality, prerequisite conditions, and lack of resources. The MitC-GERT identified loops and cycles within the overall project network structure. Due to the project activity's stochastic nature, the MitC-GERT has generated additional project network paths compared to the conventional project scheduling. The results of the simulation have proved the effectiveness of these new networks. A project manager can make a well-informed managerial decision for the mitigation measures based on a new holistic project network structure. It also proves that specific real-life project network paths are not considered in the conventional PERT distribution and following classical Monte Carlo risk analysis.

In summation, the MitC-GERT is the author's efforts to implement the concepts of GERT, probabilistic Monte Carlo Simulation, and control concepts in a software tool for the construction industry. The code for the MitC-GERT is open source, and the authors encourage modification and adding new features to the mitigation controller to be a state-of-the-art solution. The MitC-GERT in its current form requires high computational power and an understanding of the concepts of GERT for its analysis. However, the authors are focussed on improving further by increasing the efficiency of the Monte Carlo simulation for projects modelled using GERT. Furthermore, highly complex construction projects could employ the concepts of Q-GERT for a higher degree of optimisation. Future research is considered in the project network's conditional input nodes (AND, OR, XOR) domain.

Conflict of Interest

The authors wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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3

Personal Reflection

I perused the ongoing research topics available on the website of 'Open Design Learning', and the study on the mitigation controller (MitC) piqued my interest. I spent weeks meticulously reading through all the available publications on the MitC to understand the simulation tool. The limitations mentioned by the original developer of the MitC sparked the idea for formulating my current thesis topic.

I had a great deal of supplementary assistance in translating the project information from Dutch to English while preparing the input data for the MitC-GERT. Furthermore, after presenting my prototype at the company, I met with some interesting applications for the tool. One senior project manager enquired about its applicability to a nuclear powerplant, where one of the objective functions is to consider the daily radiation levels to analyse construction delays. After preparing the input files with the company's help, I worked on the rest of the thesis predominantly on my own. I referred to the open source code published in the GitHub repository of the original MitC and used it as my basis for developing MitC-GERT. I noticed that the code was well documented and split into logical modules for programmers and researchers to understand the operation of MitC. I carefully extracted the code required to function while adding my own to support the GERT distribution mentioned in my thesis. The course, 'Engineering System Optimisation', provided a good base for tackling an optimisation model in MATLAB. After constructing the MitC-GERT, I entered the verification and validation phase. During this phase, I noticed that the original MitC had certain difficulties handling a more significant number of activities for its analysis. When I ran my input file of 138 activities in the original MitC, I encountered a runtime error saying the maximum time limit for searching an optimal value had exceeded. This runtime error can also be based on the input files. I changed the 'Maxtime' value from five seconds to twenty-five seconds to approximate my required optimal solution.

After my verification and validation, I noticed that the optimisation could be further refined by using a novel Monte Carlo Analysis, which led to my second delta. Upon its implementation, project managers at my company pointed out its application to their other projects, and the probability of occurrence of activity was a good indicator of their internal efficiency within the company. Specific markers were raised in their next quarterly meeting to address the lag in approving a particular design procedure. They also noticed a potentially massive cost overrun if they entered a specific project path, the reason this analysis was omitted was because of its modest probability of occurrence, but the ramifications were massive. Thus, the project managers ensured they did not enter that project path. Therefore, This tool is good guidance to project managers to understand the brevity of the project cost overruns if they traverse other project paths.

My suggestions for future research on this topic would be implementing the Queuing-Graphical Evaluation and Review Technique (Q-GERT). Highly complex construction projects sometimes require a sequence of project activity realisation in order to ensure project success. It is especially beneficial for projects that require conditional probability and queueing theory. Furthermore, Implement this code in MATLAB Simulink for better efficiency. My areas of improvement could be writing a neater MATLAB code with lesser FOR LOOPS for better efficiency. Features like Rapid Accelerator & Rapid Restart will help reduce the system's computational power by fixing a specific memory for repetitive commands. Monte Carlo Simulation is a good example of running this function.

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A

Appendix : Input spreadsheet of project activities for PERT Distribution

1	2	3	4	5	6
Activity ID	Activity description	Duration (days)			Predecessor activities
		Optimistic	Most-Likely	Pessimistic	
1	Submit offer (21-02-2022)	14	15	18	
2	Preliminary contract award (17-02-2022)	12	13	16	1
3	Point of no return: start phase 'Preparation works'	14	15	18	1
4	Drawing up sub-plan: H&S (dimensions), elaboration of management sys/plan, digital measurement, pre-d	14	15	18	1
5	Coordination with OG plan: H&S (dimensions), elaboration of management sys/plan, digital measurement, pre-d	11	12	15	4
6	Identifying interfaces in Interface Control Forms (ICF)	54	60	72	2
7	Contract award/signing (08-04-2022)	14	15	18	2

8	Acceptance term OG plan: H&S (dimensions), elaboration of management sys/plan, digital measurement, pre-d	18	20	24	5
9	Digital measurement of existing situation (scan) (3x during a night closure)	122	135	162	2
10	Requirements interpretation and validation installations IA	77	85	102	7
11	System Requirement Review installations IA (SRR)	9	10	12	10
12	Requirements interpretation and validation Steel/Mechanical/Civil	3	3	4	9,7
13	Make final design dimensionally stable (tolerances, measurements, contruction sheer, weld details, lifting plan, installation method)	9	10	12	9,12
14	Aligning final design in a dimensionally stable manner with requirements interpretation and validation including update IC	6	6	8	13,12
15	Drafting preliminary design documents installations IA including update ICF	45	50	60	10
16	System Requirement Review Steel/Mechanial/Civil (SRR)	14	15	18	12
17	System Design Review (SDR)	9	10	12	15
18	Period of preliminary consultation on permits/ coordination with RWS	36	40	48	15
19	Delivery time steel for bridge deck and tooth track	119	132	159	7
20	Shop drawings steel including update ICF	5	5	6	19
21	Making mold-shaped cover plates	12	13	16	19
22	Cutting plates for troughs	14	15	18	22
23	Set troughs	2	2	3	15

24	Drafting final design documents installation IA including update ICF	5	5	6	19,21
25	Cutting boards for deck, main and deck girders	41	45	54	24
26	Preliminary Design Review (SDR)	5	5	6	14,13
27	Production tooth track	5	5	6	19
28	Drafting shop drawings documents installations IA including update ICF	5	5	6	24
29	Delivery time LFV's installations IA	4	4	5	24
30	Procedural period/ extension period/ objection period permits	30	33	40	28
31	FAT LFVs for IFAT in Delft (Building blocks, CCTV, Audio, LIB-LIV, Signals, Traffic barriers, network)	9	10	12	30
32	Critical Design Review (CDR)	9	10	12	28
33	Shop drawings steel including update ICF - no longer critical	78	86	104	20
34	Delivery time bridge control system (LFV)	14	15	18	15
35	Point of no return: start phase 'Preparation outside' (Start of maritime obstruction)	77	85	102	7,32,26,17,11
36	Remove emergency power generation (including wall)	2	2	3	35
37	Step 06a: FAT Delft 3BB by RWS/ON-3BB	27	30	36	35
38	Setting up pontoons at construction site	2	2	3	35
39	FAT control drive	9	10	12	34
40	Start SLOT - Blockage of maritime traffic (02-01-2023)	14	15	18	7,35
41	Start work on-site	0	0	0	35,3
42	Extend technical room	1	1	2	36,38
43	Fix deck and remove shell and pinion shaft	9	9	11	38
44	Applying overpressure installation technical room	4	4	5	42
45	Production tooth track segments	5	5	6	20,14

46	Moving existing IA equipment (including dust-free screening)	2	2	3	48,43
47	Make bridge function-free and connect construction power house	1	1	2	46,43
48	Technical room available	5	5	6	44
49	Remove cables from existing IA equipment	13	14	17	47
50	Build and assemble bridge deck with ballast box	3	3	4	23,25
51	Assembly of the tooth track anchor and tooth track segments	30	33	40	27,45
52	Dimension Control	3	3	4	50
53	IFAT LFVs part 1 (Building blocks, CCTV, Audio, LIB-LIV, Signals, Barrier traffic, Network)	41	45	54	31
54	Install cable ducts in the basement (ceiling and wall)	8	8	10	49
55	Making to the basement entrance door (including roller shutter)	2	2	3	38
56	Boring shaft and consoles for moving work deck	14	15	18	52
57	Moving from IFAT location to TR (pontoon) part 1 (Building blocks, Video, Audio, LIB-LIV, Signals, Brrs.)	4	4	5	53
58	Measuring tooth track at VDS (FAT)	14	15	18	45,51
59	IFAT 3B2Go with complete setup of bridge deck	41	45	54	39,31
60	Installing cabling within TR part 1 (Building blocks, Video, Audio, LIB-LIV, Signals)	135	150	180	57
61	Connecting cabling with LFVs part 1 (Building blocks, Video, Audio, LIB-LIV, Signals)	2	2	3	60
62	Pulling cables	4	4	5	54
63	Demolition concrete tooth track including moving gear and 4 point lift system	7	7	9	55

64	Step 06b: FAT GWW 3BB (specifically at IFAT location) by RWS/ON-3BB	60	66	80	37
65	Install outdoor equipment (LFVs)	9	10	12	62
66	Install indoor equipment (LFVs)	5	5	6	62,34
67	IFAT J15/31 sign + maritime signal and for emergency operation	5	5	6	64,59
68	Moving from IFAT location to TR (pontoon) part 2 (3BB, J15/31 sign + maritime signal and bridge decks)	17	18	22	67
69	Commisioning part 1 (Building blocks, CCTV, Audio, LIB-LIV, Signals, Network)	5	5	6	61,66,65
70	Preserving the deck - Part A to D	14	15	18	56
71	Install cabling within technical room part 2 (3BB, J15/31 board + maritime signal and bridge deck)	5	5	6	68
72	Placing barriers new deck	41	45	54	70
73	Install railing deck	4	4	5	56,70
74	SAT (Building Blocks, CCTV, Audio, LIB-LIV, Signals, network)	9	9	11	31,69,53
75	Apply control ballast	9	10	12	70
76	Make supporting columns pillar 10	2	2	3	43
77	Applying movement work to consoles on ballast box deck including alignment	60	66	80	56,70,59
78	Reinforce main pivots points east and west	8	8	10	55
79	ISAT LFVs (Building Blocks, CCTV, Audio, LIB-LIV, Signals, barrier traffic, Network)	9	10	12	74
80	3-point measurement weight/ support pressure/ deformation/ sag deck (FAT bridge deck)	5	5	6	77,73,72,52
81	Construction of the concrete construction of the new tooth track	12	13	16	63

82	Dimensions concrete new tooth track	26	28	34	63
83	Placing shafts and inner bearing seats on mounting platform	9	10	12	56,70,80
84	Buffer IA work for start SLOT road traffic	12	13	16	60
85	Buffer production bridge deck for start of SLOT road traffic	8	8	10	80
86	Buffer civil/WTB work for the start of SLOT (road traffic)	38	42	51	82
87	Point of no return: start phase 'Blocking road traffic'	70	77	93	7
88	Start SLOT - Blockage of road traffic (12-06-2023)	21	23	28	41,87,84,85,86
89	Remove barriers and asphalt basement roof	9	9	11	88
90	Remove barriers bridge (north and south)	4	4	5	88
91	Concrete work pillar 10 (excluding curing)	2	2	3	88,90
92	Removal of roof girders existing basement roof	1	1	2	88,89
93	Lifting out existing bridge deck	2	2	3	92,91
94	Cutting through axes main pivots with thermal lance	15	16	20	93
95	Lifting out anchors main pivots bridge deck	8	8	10	93,94
96	Hoisting in new tooth track	5	5	6	59,58,81
97	Adjusting foundation for anchors main pivot points bridge deck	2	2	3	95
98	Transport deck to Haringvlietbridge	2	2	3	80
99	Placing, adjusting, pouring, and curing anchors main pivots	4	4	5	97
100	Hoisting deck with shafts and inner bearing seats including sets main pivot points	2	2	3	96,98,99,91,78,76
101	Converting trestle for lifting basement roof	6	6	8	100
102	Hoisting in prefab basement roof	2	2	3	100,101
103	Measuring the position of the tooth track in the basement	9	10	12	104

104	Applying anchors, setting and casting with edilon (including curing for 48 hours)	41	45	54	96,100
105	Pre-tension anchors tooth track	30	33	40	104
106	Sealing joints and pouring basement roof (including removal of mortars)	6	6	8	102
107	Concrete work transition pieces left and right of the bridge deck	9	10	12	102
108	Placing and pouring steel transition pieces pillar 10 (including curing)	1	1	2	100,91
109	Connecting bridge deck system (drive (main/auxiliary), motor control, sensors, brake, attachments	24	26	32	105,59
110	Removal of asphalt on bridge (north and south)	23	25	30	90,108
111	Repair membrane bridge (north and south)	2	2	3	110
112	Asphalting bridge (north and south) including cleaning and testing	6	6	8	111
113	Road marking bridge (north and south)	2	2	3	112
114	Commissioning the drive	12	13	16	103,109
115	Placing and pouring steel transition pieces at the front/back of the basement roof	8	8	10	102, 106,107
116	Asphalting basement roof	13	14	17	115,106
117	Placing barriers bridge (north and south)	11	12	15	113
118	Placing traffic barriers (north and south)	12	13	16	117
119	Road marking bridge deck and basement roof	2	2	3	116,113
120	Placing barriers basement roof including hook/ridge construction	2	2	3	116,108,90
121	ISAT bridge deck, MTM portals, signals, J15/31 sign and barriers	65	70	75	114,79,118,109, 120
122	SIT including recovery and retests	4	4	5	121

123	SIT-O	4	4	5	122
124	Update technical file with as-built	14	15	18	41
125	Retest SIT-O	2	2	3	123,124
126	End of SLOT - Road traffic blockage (30-07-2023)	27	30	36	117,128
127	Point of no return: start phase 'Finishing the work'	14	15	18	121,126
128	Buffer to the end of SLOT road traffic	2	2	3	119
129	Object ready for use by road (30-07-2023)	0	0	0	126
130	Completing technical file CE marking	67	74	89	125,124
131	Buffer until final date II.1.A Statement/ Technnical File	54	60	72	130
132	Deadline for submission II.1.A statement/technical file	27	30	36	130,131
133	RWS process obtaining CE marking	54	60	72	130
134	CE mark issued	54	60	72	133
135	End of SLOT - Maritime traffic blockage (30-07-2023)	27	30	36	121,130
136	Object ready for use by maritime traffic	18	20	24	121,134,135,132
137	Completion of the work (30-11-2023)	14	15	18	125,129,136,127
138	Multi-year maintenance (end 31-05-2024)	14	15	18	137

B

Appendix : Input spreadsheet of project activities for GERT Distribution

1	2	3	4	5	6	7	8	9	10	11	12	13
Activity ID	Node Start	Node End	Activity description	Duration (days)			Activity Probability	Probability Start	Probability End	Estimation Activity Probability (P)	Predecessor	Original Activity
				Optimistic	Most-Likely	Pessimistic						
1	1	1	Submit offer (21-02-2022)	14	15	18	1.000	0.000	1.000	1		1
2	1	2	Preliminary contract award (17-02-2022)	12	13	16	1.000	0.000	1.000	1	1	1
3	1	3	Point of no return: start phase 'Preparation works' - Success	14	15	18	0.750	0.000	0.750	0.78	1	0
4	3	3	Point of no return: start phase 'Preparation works' - Fail	0	0	0	0.250	0.750	1.000	0.22		0
5	1	4	Drawing up sub-plan: H&S (dimensions), elaboration of management sys/plan,	14	15	18	1.000	0.000	1.000	1	1	1

			digital measurement, pre-d									
6	5	4	Rework: Coordination with OG plan: H&S (dimensions), elaboration of management sys/plan, digital measurement, pre-d	9	9	10	0.800	0.200	1.000	0.77		0
7	8	4	Redo: Acceptance term OG plan: H&S (dimensions), elaboration of management sys/plan, digital measurement, pre-d	15	16	18	0.050	0.950	1.000	0.06		0
8	4	5	Coordination with OG plan: H&S (dimensions), elaboration of management sys/plan, digital measurement, pre-d	2	3	5	0.200	0.000	0.200	0.23	5	1
9	8	5	Rework: Acceptance term OG plan: H&S (dimensions), elaboration of management sys/plan, digital measurement, pre-d	2	3	5	0.100	0.850	0.950	0.12		0
10	2	6	Identifying interfaces in Interface Control Forms (ICF)	54	60	72	1.000	0.000	1.000	1	2	1
11	2	7	Contract award/signing (08-04-2022)	14	15	18	1.000	0.000	1.000	1	2	1

12	10	7	Rework: Requirements interpretation and validation installations IA	23	25	30	0.500	0.500	1.000	0.45		0
13	5	8	Acceptance term OG plan: H&S (dimensions), elaboration of management sys/plan, digital measurement, pre-d	1	1	1	0.850	0.000	0.850	0.82	8	1
14	2	9	Digital measurement of existing situation (scan) (3x during a night closure)	122	135	162	1.000	0.000	1.000	1	2	1
15	7	10	Requirements interpretation and validation installations IA	54	60	72	0.500	0.000	0.500	0.55	11	1
16	11	10	Rework: System Requirement Review installations IA (SRR)	7	7	7	0.100	0.900	0.100	0.05		0
17	15	10	Rework: Drafting preliminary design documents installations IA including update ICF	27	30	36	0.500	0.500	1.000	0.45		0
18	10	11	System Requirement Review installations IA (SRR)	2	3	5	0.900	0.000	0.900	0.95	15	1
19	7	12		0	0	0	1.000	0.000	1.000	1		0
20	9	12	Requirements interpretation and validation Steel/Mechanical/Civil	21	23	28	1.000	0.000	1.000	1	11,14	1
21	9	13		0	0	0	1.000	0.000	1.000	1		0

22	12	13	Make final design dimensionally stable (tolerances, measurements, contruction sheer, weld details, lifting plan, installation method)	9	10	12	1.000	0.000	1.000	1	14,20	1
23	12	14		0	0	0	1.000	0.000	1.000	1		0
24	13	14	Aligning final design in a dimensionally stable manner with requirements interpretation and validation including update IC	6	6	8	1.000	0.000	1.000	1	20,22	1
25	10	15	Drafting preliminary design documents installations IA including update ICF	9	10	12	0.500	0.000	0.500	0.55	15	1
26	12	16	System Requirement Review Steel/Mechanial/Civil (SRR)	14	15	18	1.000	0.000	1.000	1	20	1
27	15	17	System Design Review (SDR)	9	10	12	1.000	0.000	1.000	1	25	1
28	15	18	Period of preliminary consultation on permits/ coordination with RWS	36	40	48	1.000	0.000	1.000	1	25	1
29	7	19	Delivery time steel for bridge deck and tooth track	119	132	159	1.000	0.000	1.000	1	11	1
30	20	19	Rework: Shop drawings steel including update ICF	4	4	4	0.500	0.500	1.000	0.45		0
31	19	20	Shop drawings steel including update ICF	1	1	2	0.500	0.000	0.500	0.55	29	1

32	19	21	Making mold-shaped cover plates	12	13	16	1.000	0.000	1.000	1	29	1
33	24	21	Rework: Drafting final design documents installation IA including update ICF	4	4	4	0.500	0.500	1.000	0.45		0
34	22	22	Cutting plates for troughs	14	15	18	1.000	0.000	1.000	1	32	1
35	15	23	Set troughs	2	2	3	1.000	0.000	1.000	1	29	1
36	19	24		0	0	0	1.000	0.000	1.000	1	25	0
37	21	24	Drafting final design documents installation IA including update ICF	1	1	2	0.500	0.000	0.500	0.55	29,32	1
38	24	25	Cutting boards for deck, main and deck girders	41	45	54	1.000	0.000	1.000	1	37	1
39	13	26		0	0	0	1.000	0.000	1.000	1		0
40	14	26	Preliminary Design Review (SDR)	5	5	6	1.000	0.000	1.000	1	22,24	1
41	19	27	Production tooth track	5	5	6	1.000	0.000	1.000	1	29	1
42	51	51	Rework: Assembly of the tooth track anchor and tooth track segments	5	5	6	0.400	0.600	1.000	0.35		0
43	24	28	Drafting shop drawings documents installations IA including update ICF	5	5	6	1.000	0.000	1.000	1	37	1
44	24	29	Delivery time LFV's installations IA	4	4	5	1.000	0.000	1.000	1	37	1
45	28	30	Procedural period/ extension period/ objection period permits	30	33	40	1.000	0.000	1.000	1	43	1

46	30	31	FAT LFVs for IFAT in Delft (Building blocks, CCTV, Audio, LIB-LIV, Signals, Traffic barriers, network)	2	3	5	0.700	0.000	0.700	0.75	45	1
47	31	31	Rework: FAT LFVs for IFAT in Delft (Building blocks, CCTV, Audio, LIB-LIV, Signals, Traffic barriers, network)	7	7	7	0.300	0.700	1.000	0.25		0
48	28	32	Critical Design Review (CDR)	9	10	12	1.000	0.000	1.000	1	43	1
49	20	33	Shop drawings steel including update ICF - no longer critical	27	30	36	0.500	0.000	0.500	0.6	31	1
50	33	33	Rework: Shop drawings steel including update ICF - no longer critical	24	26	32	0.500	0.500	1.000	0.4		0
51	15	34	Delivery time bridge control system (LFV)	14	15	18	1.000	0.000	1.000	1	25	1
52	7	35		0	0	0	1.000	0.000	1.000	1		0
53	11	35		0	0	0	1.000	0.000	1.000	1		0
54	17	35		0	0	0	1.000	0.000	1.000	1		0
55	26	35		0	0	0	1.000	0.000	1.000	1		0
56	32	35	Point of no return: start phase 'Preparation outside' (Start of maritime obstruction) - Success	27	30	36	0.300	0.000	0.300	0.25	11, 18,27,40, 48	0
57	35	35	Point of no return: start phase 'Preparation outside' (Start of maritime obstruction) - Fail	23	25	30	0.700	0.300	1.000	0.75		0

58	35	36	Remove emergency power generation (including wall)	2	2	3	1.000	0.000	1.000	1	56	1
59	35	37	Step 06a: FAT Delft 3BB by RWS/ON-3BB	5	5	6	0.800	0.000	0.800	0.83	56	1
60	37	37	Rework: Step 06a: FAT Delft 3BB by RWS/ON-3BB	17	20	24	0.200	0.800	0.200	0.17		0
61	35	38	Setting up pontoons at construction site	2	2	3	1.000	0.000	1.000	1	56	1
62	34	39	FAT control drive	2	2	3	0.900	0.000	0.900	0.92	51	1
63	39	39	Rework: FAT control drive	5	6	6	0.200	0.900	1.000	0.08		0
64	7	40		0	0	0	1.000	0.000	1.000	1		0
65	35	40	Start SLOT - Blockage of maritime traffic (02-01-2023)	14	15	18	1.000	0.000	1.000	1	11,56	1
66	3	41		0	0	0	1.000	0.000	1.000	1		0
67	35	41	Start work on-site	0	0	0	1.000	0.000	1.000	1	4,56	1
68	36	42		0	0	0	1.000	0.000	1.000	1		0
69	38	42	Extend technical room	1	1	2	1.000	0.000	1.000	1	58,61	1
70	38	43	Fix deck and remove shell and pinion shaft	9	9	11	1.000	0.000	1.000	1	61	1
71	42	44	Applying overpressure installation technical room	4	4	5	1.000	0.000	1.000	1	69	1
72	14	45		0	0	0	1.000	0.000	1.000	1		0
73	20	45	Production tooth track segments	5	5	6	1.000	0.000	1.000	1	24,31	1
74	43	46		0	0	0	1.000	0.000	1.000	1		0
75	48	46	Moving existing IA equipment (including dust-free screening)	2	2	3	1.000	0.000	1.000	1	70,78	1
76	43	47		0	0	0	1.000	0.000	1.000	1		0

77	46	47	Make bridge function-free and connect construction power house	1	1	2	1.000	0.000	1.000	1	70,75	1
78	44	48	Technical room available	5	5	6	1.000	0.000	1.000	1	71	1
79	47	49	Remove cables from existing IA equipment	13	14	17	1.000	0.000	1.000	1	77	1
80	23	50		0	0	0	1.000	0.000	1.000	1		0
81	25	50	Build and assemble bridge deck with ballast box	3	3	4	1.000	0.000	1.000	1	35,38	1
82	27	51		0	0	0	1.000	0.000	1.000	1		0
83	45	51	Assembly of the tooth track anchor and tooth track segments	30	33	40	0.600	0.000	0.600	0.65	41,73	1
84	50	52	Dimension Control	3	3	4	1.000	0.000	1.000	1	81	1
85	31	53	IFAT LFVs part 1 (Building blocks, CCTV, Audio, LIB-LIV, Signals, Barrier traffic, Network)	14	15	18	0.500	0.000	0.500	0.55	46	1
86	53	53	Rework: IFAT LFVs part 1 (Building blocks, CCTV, Audio, LIB-LIV, Signals, Barrier traffic, Network)	13	15	18	0.500	0.500	1.000	0.45		0
87	49	54	Install cable ducts in the basement (ceiling and wall)	8	8	10	1.000	0.000	1.000	1	79	1
88	38	55	Making to the basement entrance door (including roller shutter)	2	2	3	1.000	0.000	1.000	1	61	1

89	52	56	Boring shaft and consoles for moving work deck	14	15	18	1.000	0.000	1.000	1	84	1
90	53	57	Moving from IFAT location to TR (pontoon) part 1 (Building blocks, Video, Audio, LIB-LIV, Signals, Brrs.)	4	4	5	1.000	0.000	1.000	1	85	1
91	45	58		0	0	0	1.000	0.000	1.000	1		0
92	51	58	Measuring tooth track at VDS (FAT)	14	15	18	1.000	0.000	1.000	1	73,83	1
93	31	59		0	0	0	1.000	0.000	1.000	1		0
94	39	59	IFAT 3B2Go with complete setup of bridge deck	14	15	18	0.900	0.000	0.900	0.88	46,62	1
95	59	59	Rework: IFAT 3B2Go with complete setup of bridge deck	11	15	18	0.100	0.900	1.000	0.12		0
96	57	60	Installing cabling within TR part 1 (Building blocks, Video, Audio, LIB-LIV, Signals)	135	150	180	1.000	0.000	1.000	1	90	1
97	60	61	Connecting cabling with LFVs part 1 (Building blocks, Video, Audio, LIB-LIV, Signals)	2	2	3	1.000	0.000	1.000	1	96	1
98	54	62	Pulling cables	4	4	5	1.000	0.000	1.000	1	87	1
99	55	63	Demolition concrete tooth track including moving gear and 4 point lift system	7	7	9	1.000	0.000	1.000	1	88	1
100	37	64	Step 06b: FAT GWW 3BB (specifically at	14	15	18	0.800	0.000	0.800	0.85	59	1

			IFAT location) by RWS/ON-3BB									
101	64	64	Rework: Step 06b: FAT GWW 3BB (specifically at IFAT location) by RWS/ON-3BB	32	36	44	0.200	0.800	1.000	0.15		0
102	62	65	Install outdoor equipment (LFVs)	9	10	12	1.000	0.000	1.000	1	98	1
103	34	66		0	0	0	1.000	0.000	1.000	1		0
104	62	66	Install indoor equipment (LFVs)	5	5	6	1.000	0.000	1.000	1	51,98	1
105	59	67		0	0	0	1.000	0.000	1.000	1		0
106	64	67	IFAT J15/31 sign + maritime signal and for emergency operation	1	1	2	0.900	0.000	0.900	0.92	94, 100	1
107	67	67	Rework: IFAT J15/31 sign + maritime signal and for emergency operation	3	3	3	0.100	0.900	1.000	0.08		0
108	67	68	Moving from IFAT location to TR (pontoon) part 2 (3BB, J15/31 sign + maritime signal and bridge decks)	17	18	22	1.000	0.000	1.000	1	106	1
109	61	69		0	0	0	1.000	0.000	1.000	1		0
110	65	69		0	0	0	1.000	0.000	1.000	1		0
111	66	69	Commisioning part 1 (Building blocks, CCTV, Audio, LIB-LIV, Signals, Network)	5	5	6	1.000	0.000	1.000	1	97, 102, 104	1
112	56	70	Preserving the deck - Part A to D	14	15	18	1.000	0.000	1.000	1	89	1

113	68	71	Install cabling within technical room part 2 (3BB, J15/31 board + maritime signal and bridge deck)	5	5	6	1.000	0.000	1.000	1	108	1
114	70	72	Placing barriers new deck	41	45	54	1.000	0.000	1.000	1	112	1
115	56	73		0	0	0	1.000	0.000	1.000	1		0
116	70	73	Install railing deck	4	4	5	1.000	0.000	1.000	1	89, 112	1
117	31	74		0	0	0	1.000	0.000	1.000	1		0
118	53	74		0	0	0	1.000	0.000	1.000	1		0
119	69	74	SAT (Building Blocks, CCTV, Audio, LIB-LIV, Signals, network)	2	2	3	0.800	0.000	0.800	0.82	46, 85, 111	1
120	74	74	Rework: SAT (Building Blocks, CCTV, Audio, LIB-LIV, Signals, network)	5	5	5	0.200	0.800	1.000	0.18		0
121	70	75	Apply control ballast	9	10	12	1.000	0.000	1.000	1	112	1
122	43	76	Make supporting columns pillar 10	2	2	3	1.000	0.000	1.000	1	70	1
123	56	77		0	0	0	1.000	0.000	1.000	1		0
124	59	77		0	0	0	1.000	0.000	1.000	1		0
125	70	77	Applying movement work to consoles on ballast box deck including alignment	60	66	80	1.000	0.000	1.000	1	89, 94, 112	1
126	55	78	Reinforce main pivots points east and west	8	8	10	1.000	0.000	1.000	1	88	1
127	74	79	ISAT LFVs (Building Blocks, CCTV, Audio, LIB-LIV, Signals, barrier traffic, Network)	2	2	3	0.900	0.000	0.900	0.92	119	1

128	79	79	Rework: ISAT LFVs (Building Blocks, CCTV, Audio, LIB-LIV, Signals, barrier traffic, Network)	5	6	6	0.100	0.900	1.000	0.08		0
129	52	80		0	0	0	1.000	0.000	1.000	1		0
130	72	80		0	0	0	1.000	0.000	1.000	1		0
131	73	80		0	0	0	1.000	0.000	1.000	1		0
132	77	80	3-point measurement weight/ support pressure/ deformation/ sag deck (FAT bridge deck)	2	2	2	0.900	0.000	0.900	0.95	84, 114, 116, 125	1
133	80	80	Rework: 3-point measurement weight/ support pressure/ deformation/ sag deck (FAT bridge deck)	1	1	2	0.100	0.900	1.000	0.05		0
134	63	81	Construction of the concrete construction of the new tooth track	12	13	16	0.700	0.000	0.700	0.75	99	1
135	81	81	Redo: Construction of the concrete construction of the new tooth track	12	13	16	0.300	0.700	1.000	0.25		0
136	63	82	Dimensions concrete new tooth track	26	28	34	1.000	0.000	1.000	1	99	1
137	56	83		0	0	0	1.000	0.000	1.000	1		0
138	70	83		0	0	0	1.000	0.000	1.000	1		0
139	80	83	Placing shafts and inner bearing seats on mounting platform	9	10	12	1.000	0.000	1.000	1	89, 112, 132	1
140	60	84	Buffer IA work for start SLOT road traffic	12	13	16	1.000	0.000	1.000	1	96	1

141	80	85	Buffer production bridge deck for start of SLOT road traffic	8	8	10	1.000	0.000	1.000	1	132	1
142	82	86	Buffer civil/WTB work for the start of SLOT (road traffic)	38	42	51	1.000	0.000	1.000	1	136	1
143	7	87	Point of no return: start phase 'Blocking road traffic'	27	30	36	0.800	0.000	0.800	0.82	142	1
144	87	87	Point of no return: start phase 'Blocking road traffic' - Fail	16	17	21	0.200	0.800	1.000	0.18		0
145	41	88		0	0	0	1.000	0.000	1.000	1		0
146	84	88		0	0	0	1.000	0.000	1.000	1		0
147	85	88		0	0	0	1.000	0.000	1.000	1		0
148	86	88		0	0	0	1.000	0.000	1.000	1		0
149	87	88	Start SLOT - Blockage of road traffic (12-06-2023)	21	23	28	1.000	0.000	1.000	1	67, 140, 141, 142, 143	1
150	88	89	Remove barriers and asphalt basement roof	9	9	11	1.000	0.000	1.000	1	149	1
151	88	90	Remove barriers bridge (north and south)	4	4	5	1.000	0.000	1.000	1	149	1
152	88	91		0	0	0	1.000	0.000	1.000	1		0
153	90	91	Concrete work pillar 10 (excluding curing)	2	2	3	1.000	0.000	1.000	1	149, 151	1
154	88	92		0	0	0	1.000	0.000	1.000	1		0
155	89	92	Removal of roof girders existing basement roof	1	1	2	1.000	0.000	1.000	1	153, 150	1
156	91	93		0	0	0	1.000	0.000	1.000	1		0
157	92	93	Lifting out existing bridge deck	2	2	3	1.000	0.000	1.000	1	153, 155	1

158	93	94	Cutting through axes main pivots with thermal lance	15	16	20	1.000	0.000	1.000	1	157	1
159	93	95		0	0	0	1.000	0.000	1.000	1		0
160	94	95	Lifting out anchors main pivots bridge deck	8	8	10	1.000	0.000	1.000	1	157, 158	1
161	58	96		0	0	0	1.000	0.000	1.000	1		0
162	59	96		0	0	0	1.000	0.000	1.000	1		0
163	81	96	Hoisting in new tooth track	5	5	6	1.000	0.000	1.000	1	92. 94, 134	1
164	95	97	Adjusting foundation for anchors main pivot points bridge deck	2	2	3	0.500	0.000	0.500	0.55	160	1
165	97	97	Rework: Adjusting foundation for anchors main pivot points bridge deck	2	2	3	0.500	0.500	1.000	0.45		0
166	80	98	Transport deck to Haringvlietbridge	2	2	3	1.000	0.000	1.000	1	132	1
167	97	99	Placing, adjusting, pouring, and curing anchors main pivots	4	4	5	0.800	0.000	0.800	0.82	164	1
168	99	99	Rework: Placing, adjusting, pouring, and curing anchors main pivots	4	4	5	0.200	0.800	1.000	0.18		0
169	76	100		0	0	0	1.000	0.000	1.000	1		0
170	78	100		0	0	0	1.000	0.000	1.000	1		0
171	91	100		0	0	0	1.000	0.000	1.000	1		0
172	96	100		0	0	0	1.000	0.000	1.000	1		0
173	98	100		0	0	0	1.000	0.000	1.000	1		0
174	99	100	Hoisting deck with shafts and inner bearing seats	2	2	3	1.000	0.000	1.000	1	122, 126, 153, 163, 166, 167	1

			including sets main pivot points									
175	100	101	Converting trestle for lifting basement roof	6	6	8	1.000	0.000	1.000	1	174	1
176	100	102		0	0	0	1.000	0.000	1.000	1		0
177	101	102	Hoisting in prefab basement roof	2	2	3	1.000	0.000	1.000	1	174, 175	1
178	104	103	Measuring the position of the tooth track in the basement	9	10	12	1.000	0.000	1.000	1	177	1
179	96	104		0	0	0	1.000	0.000	1.000	1		0
180	100	104	Applying anchors, setting and casting with edilon (including curing for 48 hours)	41	45	54	1.000	0.000	1.000	1	163, 174	1
181	104	105	Pre-tension anchors tooth track	30	33	40	1.000	0.000	1.000	1	180	1
182	102	106	Sealing joints and pouring basement roof (including removal of mortars)	6	6	8	1.000	0.000	1.000	1	177	1
183	102	107	Concrete work transition pieces left and right of the bridge deck	9	10	12	1.000	0.000	1.000	1	177	1
184	91	108		0	0	0	1.000	0.000	1.000	1		0
185	100	108	Placing and pouring steel transition pieces pillar 10 (including curing)	1	1	2	1.000	0.000	1.000	1	153, 174	1
186	59	109		0	0	0	1.000	0.000	1.000	1		0
187	105	109	Connecting bridge deck system (drive (main/auxiliary), motor control, sensors, brake, attachments	24	26	32	1.000	0.000	1.000	1	94, 181	1

188	90	110		0	0	0	1.000	0.000	1.000	1		0
189	108	110	Removal of asphalt on bridge (north and south)	23	25	30	1.000	0.000	1.000	1	151, 185	1
190	110	111	Repair membrane bridge (north and south)	2	2	3	1.000	0.000	1.000	1	189	1
191	111	112	Asphalting bridge (north and south) including cleaning and testing	6	6	8	1.000	0.000	1.000	1	190	1
192	112	113	Road marking bridge (north and south)	2	2	3	1.000	0.000	1.000	1	191	1
193	103	114		0	0	0	1.000	0.000	1.000	1		0
194	109	114	Commissioning the drive	12	13	16	1.000	0.000	1.000	1	178, 187	1
195	102	115		0	0	0	1.000	0.000	1.000	1		0
196	106	115		0	0	0	1.000	0.000	1.000	1		0
197	107	115	Placing and pouring steel transition pieces at the front/back of the basement roof	8	8	10	1.000	0.000	1.000	1	177, 182, 183	1
198	106	116		0	0	0	1.000	0.000	1.000	1		0
199	115	116	Asphalting basement roof	13	14	17	1.000	0.000	1.000	1	182, 197	1
200	113	117	Placing barriers bridge (north and south)	11	12	15	1.000	0.000	1.000	1	192	1
201	117	118	Placing traffic barriers (north and south)	12	13	16	1.000	0.000	1.000	1	200	1
202	113	119		0	0	0	1.000	0.000	1.000	1		0
203	116	119	Road marking bridge deck and basement roof	2	2	3	1.000	0.000	1.000	1	192, 199	1
204	90	120		0	0	0	1.000	0.000	1.000	1		0
205	108	120		0	0	0	1.000	0.000	1.000	1		0

206	116	120	Placing barriers basement roof including hook/ridge construction	2	2	3	1.000	0.000	1.000	1	151, 185, 199	1
207	79	121		0	0	0	1.000	0.000	1.000	1		0
208	109	121		0	0	0	1.000	0.000	1.000	1		0
209	114	121		0	0	0	1.000	0.000	1.000	1		0
210	118	121		0	0	0	1.000	0.000	1.000	1		0
211	120	121	ISAT bridge deck, MTM portals, signals, J15/31 sign and barriers	22	24	29	0.700	0.000	0.700	0.75	127, 187, 194, 201, 206	1
212	121	121	Rework: ISAT bridge deck, MTM portals, signals, J15/31 sign and barriers	22	24	25	0.300	0.700	1.000	0.25		0
213	121	122	SIT including recovery and retests	1	1	2	0.800	0.000	0.800	0.82	211	1
214	122	122	Rework: SIT including recovery and retests	1	1	1	0.200	0.800	0.200	0.18		0
215	122	123	SIT-O	1	1	2	0.900	0.000	0.900	0.91	213	1
216	123	123	Rework: SIT-O	1	1	1	0.100	0.900	1.000	0.09		0
217	41	124	Update technical file with as-built	14	15	18	1.000	0.000	1.000	1	67	1
218	123	125		0	0	0	1.000	0.000	1.000	1		0
219	124	125	Retest SIT-O	2	2	3	1.000	0.000	1.000	1	215, 217	1
220	117	126		0	0	0	1.000	0.000	1.000	1		0
221	128	126	End of SLOT - Road traffic blockage (30-07-2023)	27	30	36	1.000	0.000	1.000	1	200	1
222	121	127		0	0	0	1.000	0.000	1.000	1		0

223	126	127	Point of no return: start phase 'Finishing the work'	14	15	18	1.000	0.000	1.000	1	211, 221	1
224	119	128	Buffer to the end of SLOT road traffic	2	2	3	1.000	0.000	1.000	1	203	1
225	126	129	Object ready for use by road (30-07-2023)	0	0	0	1.000	0.000	1.000	1	221	1
226	124	130		0	0	0	1.000	0.000	1.000	1		0
227	125	130	Completing technical file CE marking	22	24	29	0.900	0.000	0.900	0.92	217, 219	1
228	130	130	Rework: Completing technical file CE marking	23	26	31	0.100	0.900	1.000	0.08		0
229	130	131	Buffer until final date II.1.A Statement/ Technnical File	54	60	72	1.000	0.000	1.000	1	227	1
230	130	132		0	0	0	1.000	0.000	1.000	1		0
231	131	132	Deadline for submission II.1.A statement/technical file	27	30	36	1.000	0.000	1.000	1	227, 229	1
232	130	133	RWS process obtaining CE marking	54	60	72	1.000	0.000	1.000	1	227	1
233	133	134	CE mark issued	54	60	72	1.000	0.000	1.000	1	232	1
234	121	135		0	0	0	1.000	0.000	1.000	1		0
235	130	135	End of SLOT - Maritime traffic blockage (30-07-2023)	27	30	36	1.000	0.000	1.000	1	211, 227	1
236	121	136		0	0	0	1.000	0.000	1.000	1		0
237	132	136		0	0	0	1.000	0.000	1.000	1		0
238	134	136		0	0	0	1.000	0.000	1.000	1		0
239	135	136	Object ready for use by maritime traffic	18	20	24	1.000	0.000	1.000	1	211, 231, 233, 235	1
240	125	137		0	0	0	1.000	0.000	1.000	1		0
241	127	137		0	0	0	1.000	0.000	1.000	1		0

242	129	137		0	0	0	1.000	0.000	1.000	1		0
243	136	137	Completion of the work (30-11-2023)	14	15	18	1.000	0.000	1.000	1	219, 223, 225,239	1
244	137	138	Multi-year maintenance (end 31-05-2024)	14	15	18	1.000	0.000	1.000	1	243	1

Appendix : Input spreadsheet of risk events

7	8	9	10	11	12	13	14	15	16
Mitigation ID	Mitigation measure description	Mitigation capacity (days)			Mitigation cost (euros)				Relations with activities
		Minimum	Most likely	Maximum	dependency factor (eta)	Minimum (not user input)	Most likely	Maximum (not user input)	
1	1. Perform Inspections on Critical Components 2. Survey	1	1	1	0.5	6400	8,000	9600	97
2	Appointing key officer CE marking during the entire project (required by contract). This person guarantees file formation from day 1	31	47	62	0.5	116170.21 28	140,000	162340.42 55	130
3	1. Not too many part-time people, rather one person fulfilling two roles than two part-timers 2. Support of senior management 3. After handing in, start with PMP/key officers/other plans	3	5	6	0.5	4000	5,000	5500	6
4	1. Not too many part-time people, rather one person fulfilling two roles than two part-timers 2. Support of senior management 3. After handing in, start with PMP/key officers/other plans	3	5	6	0.5	4000	5,000	5500	10

5	Duplicate test teams not interacting at work	0	1	1	0.5	12500	25,000	25000	67
6	Duplicate test teams not interacting at work	0	1	1	0.5	12500	25,000	25000	59
7	Duplicate test teams not interacting at work	0	1	1	0.5	12500	25,000	25000	53
8	Duplicate test teams not interacting at work	0	1	1	0.5	12500	25,000	25000	125
9	Duplicate test teams not interacting at work	0	1	1	0.5	12500	25,000	25000	29
10	Duplicate test teams not interacting at work	0	1	1	0.5	12500	25,000	25000	123
11	Duplicate test teams not interacting at work	0	1	1	0.5	12500	25,000	25000	122
12	Duplicate test teams not interacting at work	0	1	1	0.5	12500	25,000	25000	121
13	Duplicate test teams not interacting at work	0	1	1	0.5	12500	25,000	25000	79
14	Duplicate test teams not interacting at work	0	1	1	0.5	12500	25,000	25000	74
15	Movement work does not function properly	31	47	62	0.5	4148.9361 7	5,000	5797.8723 4	121
16	Include in size check	2	3	4	0.5	402.17391 3	500	586.95652 17	80
17	Application included in tender phase	14	23	31	0.5	1800	2,000	2200	9
18	1. Using static scans (more accurate) 2. Attention to temperature during scanning due to distortion differences 3. Ntb	5	8	10	0.5	24375	30,000	33750	58

	specification of scanner(s) 4. No traffic during scanning due to vibrations! 5. Establish an integral surveying basis for scanning, so that measurements are performed based on the same reference 6. Include measurement errors in the tolerance plan 7. Deploy an external inspector								
19	1. Perform tolerance analysis during design phase. 2. Working together in one integral 3D model that is managed by the integral design manager in the overarching design team. 3. Place a monitoring system to measure deformations. The knowledge and expertise of Hyrde (specialised in monitoring settlements) is used for this.	5	8	10	0.5	24375	30,000	33750	81
20	1. As many full-time employees as possible 2. Create products in phases. 3. Prepare a deliverable list and monitor progress. Make timely adjustments if possible. 4. Weekly lean planning 5. Engaging two engineering firms = larger pool of knowledge and skills to adjust	1	1	1	0.5	4000	5,000	5000	28
21	1. As many full-time employees as possible 2. Create products in phases. 3. Prepare a deliverable list and monitor progress. Make timely adjustments if possible. 4. Weekly lean planning 5. Engaging two engineering firms = larger pool of knowledge and skills to adjust	1	1	1	0.5	4000	5,000	5000	20
22	1. As many full-time employees as possible 2. Create products in phases. 3. Prepare a deliverable list and monitor progress. Make timely adjustments if possible. 4. Weekly lean planning 5. Engaging two engineering firms = larger pool of knowledge and skills to adjust	1	1	1	0.5	4000	5,000	5000	24
23	1. As many full-time employees as possible 2. Create products in phases. 3. Prepare a deliverable list and monitor progress. Make	1	1	1	0.5	4000	5,000	5000	13

	timely adjustments if possible. 4. Weekly lean planning 5. Engaging two engineering firms = larger pool of knowledge and skills to adjust								
24	1. As many full-time employees as possible 2. Create products in phases. 3. Prepare a deliverable list and monitor progress. Make timely adjustments if possible. 4. Weekly lean planning 5. Engaging two engineering firms = larger pool of knowledge and skills to adjust	1	1	1	0.5	4000	5,000	5000	15
25	1. As many full-time employees as possible 2. Create products in phases. 3. Prepare a deliverable list and monitor progress. Make timely adjustments if possible. 4. Weekly lean planning 5. Engaging two engineering firms = larger pool of knowledge and skills to adjust	1	1	1	0.5	4000	5,000	5000	6
26	1. As many full-time employees as possible 2. Create products in phases. 3. Prepare a deliverable list and monitor progress. Make timely adjustments if possible. 4. Weekly lean planning 5. Engaging two engineering firms = larger pool of knowledge and skills to adjust	1	1	1	0.5	4000	5,000	5000	10
27	1. As many full-time employees as possible 2. Create products in phases. 3. Prepare a deliverable list and monitor progress. Make timely adjustments if possible. 4. Weekly lean planning 5. Engaging two engineering firms = larger pool of knowledge and skills to adjust	1	1	1	0.5	4000	5,000	5000	12
28	1. Use of 3 trestles for lifting action. These constructions are designed for heavy lifting work and can therefore be used flexibly, even if it appears during the execution that lifting plans have to be changed. No extra time is needed to have lifting calculations made or checked. 2. The planning takes into account the average number of days of unworkable weather in June and July over recent years. 3.	1	1	1	0.5	4000	5,000	6000	96

	Use of 3 bokken. These are less sensitive to wind than cranes. 4. work at night to compensate								
29	1. Use of 3 trestles for lifting action. These constructions are designed for heavy lifting work and can therefore be used flexibly, even if it appears during the execution that lifting plans have to be changed. No extra time is needed to have lifting calculations made or checked. 2. The planning takes into account the average number of days of unworkable weather in June and July over recent years. 3. Use of 3 bokken. These are less sensitive to wind than cranes. 4. work at night to compensate	1	1	1	0.5	4000	5,000	6000	93
30	1. Use of 3 trestles for lifting action. These constructions are designed for heavy lifting work and can therefore be used flexibly, even if it appears during the execution that lifting plans have to be changed. No extra time is needed to have lifting calculations made or checked. 2. The planning takes into account the average number of days of unworkable weather in June and July over recent years. 3. Use of 3 bokken. These are less sensitive to wind than cranes. 4. work at night to compensate	1	1	1	0.5	4000	5,000	6000	100
31	1. Use of 3 trestles for lifting action. These constructions are designed for heavy lifting work and can therefore be used flexibly, even if it appears during the execution that lifting plans have to be changed. No extra time is needed to have lifting calculations made or checked. 2. The planning takes into account the average number of days of unworkable weather in June and July over recent years. 3.	1	1	1	0.5	4000	5,000	6000	102

	Use of 3 bokken. These are less sensitive to wind than cranes. 4. work at night to compensate								
32	1. Use of 3 trestles for lifting action. These constructions are designed for heavy lifting work and can therefore be used flexibly, even if it appears during the execution that lifting plans have to be changed. No extra time is needed to have lifting calculations made or checked. 2. The planning takes into account the average number of days of unworkable weather in June and July over recent years. 3. Use of 3 bokken. These are less sensitive to wind than cranes. 4. work at night to compensate	1	1	1	0.5	4000	5,000	6000	92
33	Determine point of no return extrea check before we	1	1	2	0.5	4000	5,000	7000	100

D

Appendix : Input spreadsheet of mitigation measures

17	18	19	20	21	22	23
Risk event ID	Risk event description	Risk duration (days)			Affected activities	Risk probability
		Minimum	Most likely	Maximum		
1	Re-use of anchors from the main pivots (proposed in the reference design) does not appear to be possible (without adjustments).	24	40	56	97	0.375
2	File for CE marking is not ready in time	30	60	180	130	0.75
3	Mobilisation is taking much longer than expected	24	37	49	6	0.75
4	Mobilisation is taking much longer than expected	24	37	49	10	0.75
5	Corona ensures that test teams are disabled	1	3	4	67	0.175
6	Corona ensures that test teams are disabled	1	3	4	59	0.175
7	Corona ensures that test teams are disabled	1	3	4	53	0.175

8	Corona ensures that test teams are disabled	1	3	4	125	0.175
9	Corona ensures that test teams are disabled	1	3	4	29	0.175
10	Corona ensures that test teams are disabled	1	3	4	123	0.175
11	Corona ensures that test teams are disabled	1	3	4	122	0.175
12	Corona ensures that test teams are disabled	1	3	4	121	0.175
13	Corona ensures that test teams are disabled	1	3	4	79	0.175
14	Corona ensures that test teams are disabled	1	3	4	74	0.175
15	Movement work does not function properly	30	60	180	121	0.75
16	Unfamiliarity with settlement sensitivity terrain / slope / hall VDS	112	180	248	80	0.055
17	Investigate measurements too late or available	112	180	248	9	0.175
18	Deviations in the dimensions due to measurement errors outside the tolerances (measurement and layout) (not working in accordance with UO)	37	60	82	58	0.375
19	Bridge deck does not fit	37	60	82	81	0.175
20	Design work is running out	5	8	11	28	0.375
21	Design work is running out	5	8	11	20	0.375
22	Design work is running out	5	8	11	24	0.375
23	Design work is running out	5	8	11	13	0.375

24	Design work is running out	5	8	11	15	0.375
25	Design work is running out	5	8	11	6	0.375
26	Design work is running out	5	8	11	10	0.375
27	Design work is running out	5	8	11	12	0.375
28	Delay during work due to weather conditions	0	2	3	96	0.005
29	Delay during work due to weather conditions	0	2	3	93	0.005
30	Delay during work due to weather conditions	0	2	3	100	0.005
31	Delay during work due to weather conditions	0	2	3	102	0.005
32	Delay during work due to weather conditions	0	2	3	92	0.005
33	Accident with new bridge deck if old bridge deck has already been removed	112	180	248	100	0.055