Modelling Second Order Effects of Changes in Civil Engineering Projects

Master's Thesis

Construction Management and Engineering

Delft University of Technology

Graduation Committee

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Delft, Sep 28th, 2021

Preface

Dear reader. Before you lie the graduation, thesis titled "Modelling Second Order Effects of Changes in Civil Engineering Projects". The end result of a research undertaken as part of the requirements of the MSc Construction Management and Engineering and Delft University of Technology. This report is the result of seven months of preparation, research work, and writing.

The research was carried out at BAM that was part of LevveL consortium. The LevveL consortium has shown strong interests in the area of explaining and quantifying second order effects. Through their cooperation, it was possible to design the research project, which aims at further investigation of second order effects by using system dynamic modelling. This research was conducted based on the data from the project of reinforcing the Afsluitdijk.

We would like to make use of this foreword by thanking the members of our graduation committee, for their input, knowledge, time, and new perspectives which have been of great value for this master thesis. Special thanks go to Marian Bosch-Rekveldt, whose continuous precise feedback helped focus the research into something meaningful. Due to her supervision, we were able to conduct this research despite the numerous challenges throughout the graduation process. Furthermore, we want to thank the interviewees who found the time for providing important input for our thesis and being critical about their working field. Finally, because this is a dual thesis, we both want to spend a few words individually.

Igor: First, I want to thank my graduation partner Yassmin for her hard work and dedication to this study. Second, I want to thank my colleagues at BAM, especially our supervisors Cathelijne Flamink and Menno Selhorst, for their support during this graduation process. Third, I want to thank my family and friends for stimulating me to pursue the path that has led me to this point in my life. Thank you for your continuous support, both in good and bad times. Finally, I want to thank my fiancée Nevena, for her love, trust, patience, and unconditional support. I greatly acknowledge that I could not have done this without you all.

Yassmin: First, I would like to thank my thesis partner Igor for his commitment and hard work to this study. Second, I would like to thank Prof. Hans for proposing this challenging topic.

Third, thanks to all my colleagues at BAM; especially our supervisors Cathelijne Flamink and Menno Selhorst for their continuous support through the graduation process. Finally, I would like to thank my parents; Hoda & Gamal, and my siblings for believing in me and supporting my dream of carrying out this master's programme. It would not have been possible without you.

We hope you will enjoy reading this report, and that you will not be reluctant to get in contact for any questions or discussion about the thesis.

Yassmin Hassan & Igor Peco Delft, 28 September 2021

Executive Summary

One of the most common hurdles especially in large infrastructure projects is scope change. Scope changes negatively affect time, quality and usually lead to cost overruns due to underestimating the change order impacts on the project. There are two main categories through which the impacts could be quantified: the first and second order effects. The first order effect is the impact of the change, cost, time, quality, and risk related. The second order effects are the impacts that resulted as consequences of the first order effects such as lower labor productivity and increase in errors.

The authors found that there are insufficient studies about second order effects, and that especially the quantification of them should be more thoroughly investigated. Therefore, the purpose of this research was to analyze and quantify the second order effect due to scope change in large infrastructure projects. The approach that was used to create the model is system dynamics modelling (SDM), since several studies confirmed the success of system dynamics modelling in solving similar projects' problems in different industries. SDM can also simulate actual projects while considering the past performance of the system and the external factors. Therefore, SDM was used to analyze the dynamic behavior of the project of reinforcing the Afsluitdijk, to create continuous simulation that allowed the quantification of the second order effects.

Through the literature review and the case study, it was found that the second order effects of scope change are rework, schedule pressure, morale, overtime, productivity, hiring new staff, and office congestion. It was observed through the created dynamic hypothesis that productivity was directly impacted by morale, office congestion, schedule pressure and overtime. The simulated model showed that productivity and morale were the two most influenced factors by the scope change. The developed model is focused on the design phase of the New Sluices and it showed the impact of scope change on the project progress. The simulations resulted in 19 months of delay compared to the initial duration of the project. Moreover, further investigation showed that the impact of the second order effect contributed with 10 months of that delay.

"How could second order effects of the project scope change be quantified through system dynamics modelling?".
First, a dynamic hypothesis should be created and confirmed through literature and continuous interviews till the hypothesis reflects the project case. Second, formulas should be created for the defined variables and values should be inserted in the model based on the case data. Third, the model should be simulated, and the perceived progress should be compared with planned progress. Then, the first order progress should be compared with the planned progress to quantify the first order of effects of scope change. Finally, to quantify the influence of the second order effect of scope change, the first order effects should be deducted from the total influence of scope change.

The sub research questions of the first author "*How was morale impacted by uncertainties and risks?"* and *"What could have been done to overcome the loss of morale?"* concluded that uncertainties and risks can impact the staff morale through rework, lack of transparency, poor risk management and leadership. To overcome the loss of morale the presence of a skilled manager and implementing an effective risk management system, where all the different types of project risks are incorporated is essential. Moreover, it would have been wise to stop the project and investigate the impacts of the scope change before the decision to continue was taken. The second author's individual question" How *optimism bias did influence decision making?"* concluded that optimism bias influenced the decision-making process in the project. It was hypothesized that it resulted from the 'Accumulation of Planning Fallacy' that was happening during the iterations of the planning process. The proposed solution for overcoming optimism bias was the usage of the 'outside view', when forecasting the costs, durations, and benefits of the projects. 'Outside view' would bypass optimism bias and produce more accurate predictions.

Since the whole research was done to reflect the contractor's view on the problem, it represents only half of the views. Recommendation is given that similar research should be done to represent the client's perception of the matter. This new research should present the client's understanding of causes and consequences of second order effects provoked by scope change.

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1. Introduction

Infrastructure projects play a major factor in economic growth and social development (Berends, 2007). The Netherlands is one of the countries that is advanced in its infrastructure projects for the purpose of flood protection and reliable mobility (Brandsen & Cools, 2015). However, large infrastructure projects tend to have a poor reputation due to the cost overruns and delays, repeating themes in the media (Vreeswijk et al., 2009). In simple projects, the stakeholders have a clear vision and predictability of what might go wrong in the project and how they could fix it. On the contrary, in complex infrastructure projects there are several ambiguous and uncertain external and internal forces (Van Marrewijk et al., 2008; Koops et al., 2017). Amongst these forces are project design and project cultures and rationalities which challenge the project plan and the risk management during the project processes (Van Marrewijk et al., 2008).
This might lead to scope and design changes especially during the Front-End Engineering Design (FEED) stage**.**

1.1 Sketching the problem

The main issue of change in scope is that it influences the three major constraints of the project management triangle: scope, cost, and time (Cheng et al, 2015). Change of scope usually emerges in the form of requirements, delay in the decision-making process or a sudden lack of resources (Bakker, 2020). Scope change particularly influences two main categories; the first order and the second order effect (Cooper & Lee., 2009; Bakker, 2020). The first order effects are mainly the tangible visible costs of the changes such as additional scope, delays, and design uncertainties (Bakker, 2020). The second order effects are the impacts and consequences of the work induced by that change such as material procurement, increase in equipment cost, increase in overhead, lower productivity, decreased morale, disrupting project progress and scheduling conflicts (Hanna et al., 1999; Cheng et al., 2015). These second order effects could largely influence the project and reach a factor of 3 to 4 times the direct change costs (Cooper & Lee, 2009; Ford & Lyneis, 2019; Bakker, 2020).

Based on the impact of scope change, project managers turn to three main measures to cope with the tight schedule due to the occurring changes which are hiring additional staff, working overtime, and increasing the work intensity (Ford & Lyneis, 2019). Unfortunately, these three solutions lead to higher pressure, increase in fatigue, lower productivity, and increase in error (Bakker, 2020).

While the notion of the second order effects is common in the literature, these effects have not been properly investigated yet, and neither their influence on the project was properly quantified. The tools of Construction project management such as: work breakdown structure, Gantt Charts, PERT, etc. are insufficient for managing complex projects (Love et al., 2002). Traditional construction management tools can be used in specific details of the project's objectives, schedules, and manpower allocation. However, they are limited in analyzing the impacts of the second order effects, which could have helped in finding the adequate strategic solution for a specific project. That is why, to quantify second order effects caused by scope change, a mathematical model is required.

System dynamics modelling (SDM) methodology is suggested by several researchers over the past three decades to explore nonlinear and dynamic complexity issues involved in construction management (Williams et al., 1995; Rodrigues et al., 1996; Love et al., 1999; Mahmood et al., 2014) since it can provide a holistic view on the project management process. System dynamics (SD) can qualitatively and quantitatively identify aspects of a problem (Al-Kofahi, 2016). This can provide a better understanding of the problem and improve decision-making at a strategic level. The system dynamics model can integrate technical, organizational, human, and environmental factors, while simulating the behavior of major outputs of a project system over time (Love et al., 2002). Most importantly, SDM can determine the causes of rework in construction projects (Love et al., 1999) and quantify the second order of effects caused by change orders such as loss in productivity (Cheng et al., 2015). Applying system dynamic models in analyzing and understanding the factors that led to design errors and rework could help in diminishing the occurrence of these changes in the future (Love et al., 2000). Accordingly, the problem statement of the research is that the impacts of the second order effects, as consequences of scope change are difficult to quantify.

Research Gap:

Several studies were conducted regarding the impact of scope change on direct cost and time of infrastructure projects (Cheng et al., 2015). Some studies discussed the impact of failing to recognize the second order effect resulting from the first order effect (Cooper & Lee, 2009; Bakker, 2020). Other studies confirmed the success of system dynamics models for project management (Love et al., 2000; Cooper & Lee, 2009; Ford & Lyneis, 2019) through presenting case studies that succeeded in its objective through SDM. However, there are still insufficient studies on how to quantify the second order effect due to scope change in the construction industry through the use of system dynamic models.

1.2 Research Objectives

The objective of this research is to quantify the second order impacts resulting from the first order effect due to a change of scope. This will be done based on a practical problem that LevveL consortium had, that will be introduced in next section. While the research aims towards quantification of the impact second order effects have, it attempts to give an indication of the second order effects that the case of the LevveL consortium has with implementing a scope change during the project execution of reinforcing of the Afsluitdijk.

1.3 Practical problem

The case for this thesis is the reinforcement of the Afsluitdijk. The Afsluitdijk is one of the major dikes in the Netherlands responsible for keeping the land dry and protecting it from the sea water. The dike is located in the north of the Netherlands and was built between 1927 and 1932 (Mavroleon, 2021; BAM PPP, 2021). Now, some 90 years later, the dike is considered not safe enough, mainly due to the sea level rise. It was concluded that Afsluitdijk needs to be both heightened and reinforced (LevveL non-disclosed confidential PPT, 2021).

The responsibility for this endeavor lies with Rijkswaterstaat (RWS). RWS is part of the Dutch ministry of infrastructure and water management responsible for design, construction, and maintenance of public infrastructure projects in the Netherlands. RWS issued an open tender for the project of reinforcing the Afsluitdijk in 2016. In March 2018 the tender was awarded to the LevveL consortium. The consortium consisted of Van Oord (46%), BAM (46%) and Rebel (8%) (Mavroleon, 2021; BAM PPP, 2021). The type of contract was Design Build Finance and Maintain (DBFM). This type of contract states that the LevveL consortium is responsible for designing, building, financing the reinforcement of the Afsluitdijk, but also the maintenance for the next 25 years. The contract also stated that LevveL will get paid by RWS based on the availability of the reinforced dike.

The LevveL consortium financed the project by taking loans from the banks. The loan should cover the cost of reinforcing the Afsluitdijk and be paid back to the banks in the future, in advance planned schedule, starting when the reinforcement of the dike is completed, and LevveL gets paid by RWS. At the start of the project, mid 2018, several errors in the hydraulic boundary conditions were noticed by the project team (LevveL non-disclosed confidential PPT, 2021). There was an omission regarding the design loads and pressures on the dike and the gates of sluices caused by different tide levels on both sides of the dike. While the hydraulic boundary conditions for high tides and high waves were correct, the case for low tides and high waves was missing. This had a serious impact on the design of the new sluices. In the missing scenario of low tides and high waves, a large amount of air would be trapped in the sluices, presenting a safety risk. The risk would be caused by the pressured air that will be squeezed in the sluice by each new wave hit, until eventually iron gates of the sluices will be destroyed as the weakest link in the object (LevveL non-disclosed confidential PPT, 2021).

The problem was seriously considered from both client and contractor sides. While the technical solution to the problem was not yet in place, it was decided not to stop the project and go back to the drawing board, but to continue the project and find the solution in parallel. After investigating the problem in depth, it was found that the technical solution was not as easy as thought, and that it will have an effect on multiple activities down the chain of execution. Also, it was discovered that the issue of missing the hydraulic boundary condition impacted the design of the existing sluices as well (LevveL non-disclosed confidential PPT, 2021). In following months, there were a couple of discussions regarding whose responsibility this change in scope and design was, resulting in RWS admitting it was theirs, and the change was labeled as a "Client change".

1.4 Structure of the report

This report is divided into 10 chapters. After the introduction in Chapter 1, authors explain the design of the research in Chapter 2. There, the research questions are identified and the methodology for answering each of them is described. In Chapter 3, a literature study was performed, focusing on two topics, system dynamics modelling and scope change. In Chapter 4, the process of developing a system dynamics model is explained. Section by section authors are describing the five phases of development of the model, making first the qualitative model, and finishing with a quantitative one. Results that the model produced are shown and analyzed in Chapter 5. In the next two chapters, 6 and 7, authors go separate ways to answer their individual sub research question. Two topics that were examined in these chapters are the impact that design uncertainty and risk management have on morale, studied in Chapter 6, while the other one is about optimism bias and its influence on the decision making, studied in Chapter 7. The report is concluded in the last two chapters, Chapters 8 and 9. There, authors gave their conclusions about the research as a whole, but also discussed the limitations of it. At the end of the report, a list of references is given. In the appendix, authors added documents explaining in more detail some of the process that took place in the research.

2 Research Design

In this chapter the design of the research will be described.

2.1 Research Questions

As two master students are working on this case and this thesis together, research questions will be divided into those that will be answered with mutual effort and those answered individually. The research questions that will be shared are as follows:

Main Research question:

How can second order effects of the project scope change be quantified through system dynamics modelling?

To conduct the research in a systematic way, four sub research questions were defined, in order to guide the authors through answering the main research question.

Sub-Research Questions:

1. *What are the consequences of scope change?*
2. *How can the model qualitatively be described to show delays caused by the scope change?*
3. *How can the model quantitatively be described to show delays caused by the scope change?*
4. *How does the model perform in showing the impact of scope change?*

After completing the main research and answering the main research question, authors focus on the individual research, each answering an individual research question. The individual research questions that will be studied are as follows:

Individual Research Questions:

1. *How was morale impacted by design uncertainties and risk management & what could have been done to overcome the loss of morale?*
2. *How did optimism bias influence decision-making?*

2.2 Intended Outcomes

Intended outcome of this research, on the practical side, is a model that can help the LevveL consortium and the civil engineering industry in general both now and in the future. From a scientific point of view, the intended outcome is a model that will describe the magnitude of the second order effects. Possible use of the model by the consortium, and the industry later, can be as a tool that will simulate and analyze different scenarios, in order to create mitigation and corrective measures for the second order effects.

2.3 Research Methodology

The problem in place requires the identification and understanding of the causal links between the first order effects and the second order effects in a complex system. The system that will be modelled is defined as partly open. This is because fully closed systems in SD generate their own behavior using endogenous variables, while fully open systems in SD generate behavior using external events regardless of its past performance (Pruyt, 2019). Thus, authors agreed to model it as a partly open system, since the model should simulate a real-world project that is influenced by both past performance of the system and by other external factors as well.

While doing the literature study, researchers encountered several reports where similar problems in different industries were solved using the system dynamics modelling (SDM) methodology (Cooper, 1980; Sterman, 2000; Ibbs et al., 2005; Godlewski et al., 2012). A system dynamic model is used to quantify and explain the impact of the scope change on the project and the final costs (Ford & Lyneis, 2019). The model is set up to show what actually happened on the project. SDM is ideally suited to determine the first and second order effects and explain their origin (Ford & Lyneis, 2019). This happens by removing different groups of the first and second order effects that occurred on the project, one at a time to identify their contribution to the project overrun (Ford & Lyneis, 2019). This identification process allows project managers to learn which changes had significant impact on the project, so that identified risks could be addressed for future projects (Ford & Lyneis, 2019).

2.3.1 System Dynamics Modelling (SDM)

System Dynamics was first introduced by Jay W. Forrester in 1961 (Forrester, 1962) and it was used in visualizing the behavior of the complex systems and test systems' alternative policies through several simulations (Sterman, 2000). SDM is a tool that helps in addressing sophisticated issues in a system such as delays, feedback, and nonlinearities (Zhang et al.,2014). Since the real world is a multi-loop nonlinear feedback system (Zhang et al.,2014), it facilitates simulating our complex thinking in a scientific way.

CLD is the qualitative aspect of SDM, and it shows the causal effect relationship between the variables by linking them together in the system. Through connecting the variables together diverse loops are created and a coherent story about a particular issue is illustrated (Kim, 1999). Therefore, CLD is effective for helping the stakeholder with less technical background in understanding the complex system (Purwanto, 2019).

CLD could also be converted into a quantitative system by classifying the elements as “stocks", “flows”, or “auxiliary” variables (Peters, 2014).This is known as stock and flow diagrams (SFD). Stocks are variables that are accumulated over time, while flows are the rate of change of the input and the output in a stock variable. Auxiliary variables are other components besides stocks and flows that simplify the communication and enhance the model clarity (Sterman, 2000; Zhang et al.,2014). SFD uses equations based on the CLD structure to describe the relationships between the variables in the system (Zhang et al.,2014).

CLD and SFD are complementary; in which they can provide a holistic approach to investigate complex phenomena (Purwanto, 2019). Thus, SDM is a promising approach in applying the system thinking approach in the current project case.

Vensim is the software that will be used in simulating the LevveL case. Vensim is a SDM tool; in which the users can conceptualize, document, simulate, analyze, and optimize models of dynamics systems (Zhang et al.,2014). Depending on the CLD, a simulation model can be created in Vensim; in which SFD will be illustrated. Through relating all the variables among each other by connecting words with arrows, the model can be completed. Then the developed model can be simulated, and its behavior can be analyzed and evaluated (Akhtar, 2011; Zhang et al.,2014).

Accordingly, System Dynamics Modelling is the methodology selected for the current case study. In this study SDM will be used qualitatively and quantitatively. First a qualitative analysis will be done to explore the second order effects caused due to scope change through developing a causal loop diagram. Then a quantitative analysis will be applied using SFD to quantify the impact of the second order effects on each other and on the project costs. The SD model is built based on Sterman's approach (2000), using Vensim software to quantify and analyze the impacts of scope change.

2.3.2 Sterman's model development approach

Developing a system dynamics model is a complex process consisting of different stages. During the literature studies, authors found a couple of approaches for developing a model from scratch. As these approaches didn't differ a lot regarding the steps needed for the model development, the authors decided to use Sterman's approach (2000), as the most popular one. Sterman's book (2000) divides the modelling of a SD model in five phases as shown in Figure 1:

1. Problem Articulation
2. Dynamic Hypothesis
3. Formulating simulation model
4. Model testing
5. Policy Formulation and evaluation

The authors structured the research, so that the five phases will be applied to answering sub research questions two, three and four. This will be elaborated in Section 2.4.

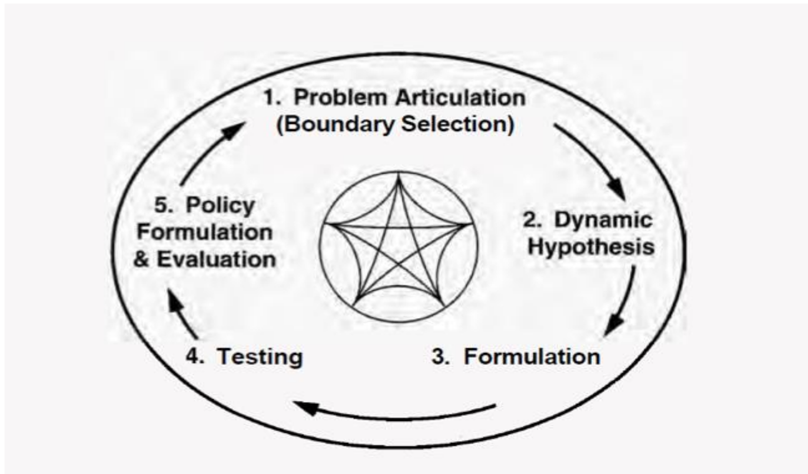


Figure 1. Iteration of modelling process (Sterman, 2000)

The process of making a SD model is very iterative and interactive; the model will have a variety of versions, as a new finding in one stage can reveal a need to redo one of the previous phases (Homer, 1996), as shown in Figure 1.

2.4 Research Approach

In this paragraph the plan for answering each research question will be introduced. To answer the main research question, "*How could the second order effect be quantified through system dynamics modelling?*" The authors approach was to first develop a basic SD model. Therefore, the authors have developed a SD model through the use of the Vensim PLE software. Vensim was chosen for practical reasons, as a free software that has all the necessary functions for developing a SD model.

To answer the first sub research question, "*What are the consequences of scope change?",* the authors conducted a literature review to identify the variables imputed by the scope change. Then semi structured interviews were conducted to confirm the identified variables with the real case of the project.

To answer the second sub-research question, "*How should the model qualitatively be described to show delays caused by the scope change?''* the first and second phases of Sterman's approach

(2000); Problem Articulation and Dynamic Hypothesis, were described and followed. First the model boundaries were identified. Subsequently, authors developed a conceptual model of factors based on the results of the literature review regarding the variables impacted by the scope change. Analyzing the literature review helped in constructing the interviews protocol with a focus on the second order effects of scope change. For this study structured and semi structured interviews were used in the qualitative research method to collect the required data from LevveL experts. The interviews involved identification of causal links between variables, identification of feedback loops created by those causal links, and finally constructing the dynamic hypothesis by combining all of the identified loops. The answer to this question was elaborated in Chapter 4, model development.

To answer the third sub-research question, "*How should the model quantitatively be described to show delays caused by the scope change?*", the third phase; formulating the simulation model will be pursued. First, the authors developed a stock-flow diagram. The stock-flow diagram was constructed based on the causal loop diagrams. The formulas and values used in the model were partially found in literature; where compatible scenarios occurred on other projects, and partially through the conducted interviews. Based on the literature and the interviews the authors created and selected the formulas that will be used in the model for the current case study. The answer to this question is elaborated in Chapter 4, model development.

To answer the fourth sub-research question, "*How does the model perform in showing the impact of scope change?".* The fourth phase of Sterman's approach (2000); model testing was used. Authors performed adequate tests suggested in literature and by system modelling experts . These tests showed if the model is fit for purpose. In other words, the tests indicated if the model was correctly simulating the case of the LevveL and quantifying the impacts of scope change on the second order effects of the project.

Finally, to answer the individual sub research questions *"How was morale impacted by uncertainties and risks?", "What could have been done to overcome the loss of morale?"*, and *"How does optimism bias influence decision-making?"* authors presented adequate approaches for answering them in Chapters 5 and 6.

2.5 Data gathering and analysis

The authors used both primary and secondary data for this research. The primary data consisted of structured and semi structured interviews with experts. According to Bless (2000) qualitative interviews are essential to explore the matter of interest in depth. This method allows the interviewees to share information with researchers in their own words and from their own perspectives (Ely et al., 1994). The structured interviews were conducted with the two design managers who worked on the design phase of the New Sluices in the project. The structured interviews helped the authors in answering the second and third sub questions in which the model was qualitatively and quantitatively developed. The structured interviews can be found in Appendix A.

Secondly, semi structured interviews were conducted, which allowed the researcher to guide the interview in certain directions, but leave room for other perspectives, ideas, and topics (Sekeran & Bougie, 2016). The semi structured interviews were conducted with two experts from LevveL as well as two experts of system dynamics modelling (SDM). The experts from LevveL helped in explaining the project case and confirming that the developed model is simulating the real project case. The SDM experts assisted in using the software and simulating the model properly to explain the case and show the impacts of the scope change.

The secondary data will involve literature review. Literature review is chosen since it will allow sharpening the theoretical framework of the research as well as identifying variables that must be considered in the research (Bless, 2000). According to Leedy (1987), the objective of literature review is not limited to identifying and analyzing the information gathered about the topic, but also to gain insight and understanding into the problem at hand. Moreover, data from LevveL will be gathered; in the form of reports and excel sheets. The reports gave more detailed information about the project and the communication between LevveL and the client during the scope change. The excel sheets included the number of people and the work hours of the people who worked on the project before and after the scope change. This data helped the authors in estimating the hiring rate, productivity, and overtime of the people before and after the scope change.

3 Literature Review

System Dynamics Modelling is the method that will be used to define and quantify the second order effects of scope change. Therefore, the literature review is divided into two main topics; SDM, and the factors that are impacted by the scope change. The first topic is how system dynamics modelling has been used in the construction industry and what were the outcomes that SDM brought to the industry. The second topic is what are the impacts of scope change; in which the authors were able to identify the second order effects of scope change and started to analyze each of these variables and study how they influence each other. To gather the scientific reports and previous research about similar topics, TU Delft repository, Research Gate, ScienceDirect and Google Scholar were used. On those platforms the following keywords were used for filtering the results: Second order effects, system dynamics modelling, construction industry, morale, schedule pressure, errors, rework, scope change, overtime, and productivity.

3.1 System Dynamics Modelling

SDM has been used in different fields of study such as project management, defence analysis and health care. It has been used legally to explain complex effects, such as delay and disruption. More than 50 companies have used system dynamics for project management on at least one project, PRA (Pharmaceutical Research Associate) alone applied SD on more than 100 projects (Ford & Lyneis, 2019). PRA has used system dynamics in more than 45 projects for delay and disruption disputes. All have been settled with an award of 50% more than with traditional disputes resolution approaches (Ford & Lyneis, 2019). Another successful use of system dynamics was by the Strathclyde Group; in which SD was used to support six delay and disruption claims ranging from U.S $ 50 million to U.S $ 350 (Ford & Lyneis, 2019). Not to mention that SDM has been increasingly used in construction engineering areas (Liu et al., 2019) such as transportation engineering, mining engineering (Yang et al., 2012), and gas engineering (Hu et al., 2010). It was used to resolve a $500 million Ingalls shipbuilding claim against the US Navy (Cooper, 1980). Since, the developed SD model allowed the analyst to detect the causes of schedule and cost overruns on two multibillion-dollar shipbuilding programs and quantified the disruption costs resulting from delays and design changes under the Navy’s responsibility. An equally important research has been conducted with the focus on the impact of changes of key project personnel during the design phase of a construction project on design production (Chapman, 1998). A developed SD model of the design process was used to explore the causes behind the loss in design productivity resulting from staff changes. The model showed that productivity loss from staff changes is due to the following reasons:

1. New staff hired to an ongoing project has to go through a learning curve to become familiar with the project details.

2. New staff hired to an ongoing project takes time to reach the level of work rate of the existing team members.

3. The work rate of the existing team members reduces because they have to break off from their normal duties to train new team members or assist them to become familiar with the project. Not to mention that the complex nature of the project information makes it difficult to be passed in totality from one individual to the next.

4. Also, the project may commence with a tight time constraint and no tolerance in staff costs if the project sponsor has set the completion date as the highest priority. In such situations, schedule pressure may place a strain on staff morale, and if staff losses occur, the design organization has considerable difficulty in recovering (Chapman, 1998).

System dynamics methodology was also used to study and investigate the impact of change and rework on project management system performance (Love et al., 2002; Ford & Lyneis, 2019). A few researchers looked at how specific dynamics such as purchaser changes, building regulations, communications, coordination and integration of the project team, and training and skill development can help or hinder a construction project management system (Love et al., 2002; Ford & Lyneis, 2019). These researches used both a case study and system dynamic modelling to reveal that there are ways to "maximize the effect of positive dynamics and minimize the effect of negative ones".

All these studies used SDM as their methodology and turned out with successful results, since SD can deal with the dynamics' complexity created by the interdependencies, feedbacks, time delays, and nonlinearities in large scale projects (Al-Kofahi, 2016). This triggered the researchers of this report to choose SDM as a promising methodology of modelling and quantifying the second order effects of scope change for the provided case study.

3.2 Scope Change

In this section, authors consider different variables that are influenced by scope change, and study each of those connections. Based on the theoretical findings presented in each of the following sections, the authors constructed a dynamical hypothesis and developed the model later in Chapter 4.

3.2.1 **Rework**

Scope change in construction projects is a common dilemma especially in a complex project as the case of reinforcing the Afsluitdijk. Rework is a major consequence of scope change leading to cost overruns and delays (Palaneeswaran, 2006; Owalabi et al., 2014; Abdul-Rahman et al., 2016). It can increase the construction cost by more than 15% of the contract price (Li & Taylor, 2014). This is due to the fact that rework is a vicious cycle that regenerates more rework leading to more complication throughout the project elongated duration and are the source of many project management challenges (Ford & Lyneis, 2019; Bakker, 2020). Managers generally include undiscovered work in work that is thought to be really done, which leads to progress overestimation (Ford & Lyneis, 2019). What makes it more intricate is that the visible costs of the rework are not the only expenses, but there are also other costs which are known as the second order effects (Cooper, 2009; Bakker, 2020). These second order effects of scope change take shape in lower staff productivity, office congestion, decreased morale, increase of errors, schedule pressure and overtime (Hanna et al., 1999; Cheng et al., 2015). All of these effects will be further elaborated in the next sections.

3.2.2 Productivity

Productivity is the main factor that is impacted by scope change and is influenced by all the mentioned second order effects of scope change. Several studies discussed the quantification of productivity loss due to scope change, especially that its impacts are underrated by the client. Using the differential method of cost calculation is inadequate since in most of the cases the cost and progress records are not available (Leonard, 1988). Therefore, an alternative method of calculation was introduced (Leonard, 1988) to measure the staff productivity based on 90 construction disputes in 57 different projects. In all these cases the contractor faced productivity loss due to the scope change. A statistical analysis is carried out in which the data of the 90 cases were collected and studied. The results showed a direct link between the change order and loss of staff productivity. A similar prominent study confirmed the effect of scope change on productivity (Ibbs, 2005) by collecting data from 162 disputed and undisputed construction projects. The impact of scope change on productivity was represented in three stages of the project: early, normal, and late timing. This study showed that the later the change the higher the impact on the staff productivity. Such results were also confirmed in another study (Hanna, 1991) that gathered data from 61 electrical and mechanical projects. It is crucial to mention that Ibbs' study showed more optimistic results regarding the impact of scope change on productivity compared to Leonard. This could be due to several factors, such as Leonard only included disputed projects, while Ibbs data consists of both disputed and undisputed projects.

3.2.3 Morale

Morale is another second order effect of scope change that is challenging to measure and quantify (Ford & Lyneis, 2019). Morale is defined as the willingness to perform assigned tasks and it's one of the factors that has a major impact on productivity (Dye, 2011). Still, the subject of morale is not widely studied in the construction industry (Saldanha, 2018). Therefore, Saldanha (2018) has conducted a study using surveys and questionnaires, targeting staff in the construction industry with a minimum of 5 years of experience. The purpose of this study was to get an indication of the reasons and impacts of morale on team performance and productivity (Saldanha, 2018). According to Saldanha (2018), the results showed a positive correlation between project performance and morale and that high morale positively impacts productivity. Decreased morale is an intangible factor that can impact the staff performance. Low morale often leads to rework resulting from poor quality due to passivity. Also, the influence of low morale can lead to staff dissatisfaction pushing them to leave the job (Dye, 2011).

3.2.4 Errors

Errors are an additional major problem in construction projects and the reasons for delays (Dosumu, 2013; Kikwasi, 2012). In literature a few definitions of errors were found, all stating that errors are unexpected outcomes that can't be purely characterized as unlucky circumstances. Reason (2006) defined errors as a planned activity that fails to achieve its intended outcome. Love and Smith (2003) defined design error "as unintended deviations from correct and acceptable practice that are avoidable". Also, it should be noted that all errors are human errors (Love, 2014). This is because people are the ones who decide what to do, how to do it, and in the end, people are the ones that have to do it.

3.2.5 Schedule Pressure

Schedule pressure can be defined as the induced demand perceived by a group to finish their work by a given deadline (Nepal, 2006). Despite the very important role that schedule plays in projects, the quantification of it hasn't been researched enough. Authors had difficulties finding any quantifiable data, apart from basic divisions in low, normal, high, and very high pressure (Nepal, 2006). As a subjective feeling, workers define the amount of schedule pressure whether a project is ahead, on or behind the schedule. When a worker perceives that the available time for completion is less than reasonably required, he will feel the schedule pressure (Brooner, 1982). In that situation, not surprisingly, productivity is often the first to be sacrificed. To cope with schedule pressure, workers usually perform work out of sequence, cut corners or selectively use the information they are given. All of these factors have a negative effect on quality thus increasing errors workers make. While in the first place it can look like some short-term progress was made, schedule pressure will affect workers motivation and increase physical and mental fatigue, eventually decreasing productivity. But the effect of schedule pressure doesn't have to be purely negative. If dosed correctly, schedule pressure can positively affect the productivity of a worker. In psychology, the relationship between performance and pressure is best represented as nonlinear. The Yerkes-Dodson law (Wickens, 2015) shows that the best performance can be achieved with intermediate pressure, of course depending on the complexity of the task itself. Below that point, boredom might appear, and the worker will be less productive and less aroused about their task, while above that point stress will appear and the worker will be less productive.

3.2.6 Overtime

When the project is falling behind the planned schedule due to scope change, project managers have three ways of coping with that, mainly: overtime, shift work, and staffing. Usually, the preferred choice for project managers is overtime, since it will result in higher progress, without the need for organization of shifts or more workers in the same space (Hanna, 2003). But this compensation technique also comes with its downsides, with fatigue and low morale, which also impacts the staff productivity.

Depending on the way the project manager uses the overtime, different results can be estimated. While working overtime for a couple of weeks can indeed increase progress, constantly working overtime will drastically and exponentially decrease the progress, productivity, and efficacy. That’s why we recognize two types of overtime, scheduled and sporadic overtime (Chang, 2017). Also, different increases in the working hours in a week will yield different results. While a working week of 45-50h will slowly increase fatigue and decrease morale, a working week of 50-60h will do it much faster (Thomas, 1992; Thomas, 1997).

3.2.7 Hiring New Staff

Another technique that project managers choose when falling behind the schedule is to hire more people. While this seems like a logical solution to increase the speed of a project, this technique also has its downsides. Brooks law (Brooks, 1995) states that adding more people to a late project will just make it later. This was explained by pointing out the time that is lost for incorporating new people in the project. Gordon and Lamb (1977) divided this time loss in three categories, namely: time loss due to new staff learning, time loss due to teaching by experienced staff, and time loss due to group communication. First one represents the time a new member needs to get familiar with the project, organizational culture, different tools used in the project and also social interactions with other members. Not to mention that the productivity of the new members will be lower than the experienced members for the first few months, since they are still getting to know their job (Chapman, 1998). Second one represents the time loss due to the teaching of new members by the experienced members. This will lower the working hours of the experienced member, because for a few months he is devoting a part of his working hours explaining the above-mentioned aspects to the newcomers. Finally, the third one represents the time lost in communication. This is a logical consequence of increasing the number of people in a team, as more people mean more meetings, emails, phone calls, etc.

3.2.8 **Office Congestion**

Office congestion is a further second order effect of scope change that can negatively influence productivity. Scope change leads to schedule pressure, therefore more people are hired to finish the work on time. However, such an aspect creates office congestion; in which more people have to work on the project in the time and place. Several studies showed that noise and distraction could increase the error and decrease productivity (Kamarulzaman et al., 2011; Sarode & Shirsath, 2012). Office congestion creates noises in the workplace that could be distracting to the staff. Noise is not only people's conversations but also equipment, tools, phone, copier, and keyboard (Loewen & Suedfeld, 1992; Kamarulzaman et al., 2011; Sarode & Shirsath, 2012). Other studies proved that the noise produced from office congestion can be demotivating and stressful especially when the job is technologically complex leading to decrease in staff morale (Evans & Johnson, 2000; Kamarulzaman et al., 2011;).

3.3 Conclusion

Through the literature review the second order effects of the scope change were identified. These factors are rework, overtime, schedule pressure, morale, productivity, hiring new staff and office congestion. Each of these factors were found to be influenced by the scope change and can influence the construction projects' progress. Moreover, it was found that overtime and schedule pressure can impact the staff morale, which will impact productivity. Furthermore, it was observed that productivity is influenced by overtime, schedule pressure, office congestion and morale. This literature review provides starting points for designing a system dynamics model that will incorporate all the mentioned factors. Using SDM will allow simulating the linear and nonlinear relations between the factors. The model will show the causes and effects of second order effects and how these second order effects are influencing each other. Later these factors will be quantified, and different scenarios will be provided and analyzed.

4 Modelling Process

In this chapter the authors describe the approach for development of the case model. The chapter is structured to follow the five phases mentioned in earlier chapters and to answer sub-research questions two, three and four. The modelling process lasted for six months, and the model went to several revisions and versions, with each new one representing the case more realistically while staying within the boundaries of findings from the literature. The authors presented the final version of the model at the end of the current chapter.

4.1 Choosing Focus Unit

Because the whole project of reinforcing the Afsluitdijk has several functioning units going through different phases simultaneously, a focus unit needs to be chosen to ease the process of the model development. The New Sluices are chosen as the focus unit for the model, because of various reasons. First, the New Sluices represent a new unit from scratch on this project. Second, it was hugely impacted by the scope changes that occurred. Finally, having in mind the two mentioned reasons, it was assumed that the model built for the New Sluices can be easily transformed to satisfy the needs of the other new units in the project, such as the migration river, new pumps, etc. Also, in agreement with LevveL experts, the authors focused their work on the design phase of the New Sluices.

4.2 Problem Articulation

The first phase is the Problem Articulation and following Sterman's book (2000) it starts by answering two questions, what is a problem and why is it a problem? LevveL as a contractor of reinforcing the Afsluitdijk was exposed to schedule change and several delays due to the scope change introduced by the client (RWS). RWS knows that the scope change is indeed introduced from their side. The scope change presented by the client impacted the amount of work that needed to be done. This also led to second order effects that impacted the project duration and caused cost overruns. Lower productivity of the staff was one of the second order effects, which affected the working rate of the project. The perceived progress was also impacted when the

Work Really Done was less than expected due to the scope change. Therefore, LevveL is trying to show the influence of the second order effects on their project costs, so they could get the compensation for their impacts as well. So, the problem for LevveL is to show and quantify the impact of the second order effects of scope change.

4.2.1 Key Variables

Based on the described problem above, several variables were important to be tackled first. These variables are known as key variables (Sterman, 2000) and shown in Fig 2.

These key variables are:

Scope Change rate: rate at which changes are occurring after the Scope Change Start.
Work to be Done: number of Work Packages that needs to be done with the respect for the whole scope of the project.
Working rate: rate at which Work Packages are completed. So, the Work Package shifts from "Work to be Done" to "Work Done".
Perceived Progress: number of Work Packages in "Work Really Done" divided by number of Work Packages in "Work done", "Work to be Done" and "Work Really Done".
Work Really Done: number of Work Packages completely finished after approval.

Other variables could be added, but this set provides a reasonable starting point for conceptualization of the feedback structure governing the dynamics.

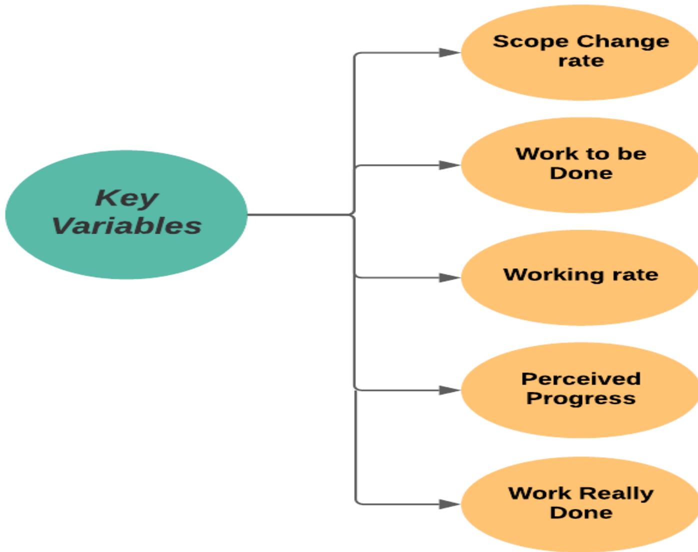


Figure 2. Identified Key Variables

**Scope Change rate >+Work to be Done >+Working rate>+Perceived Progress > +Work Really Done> - Work to be Done (Balancing Loop).*

The expected feedback from the identified key variables is that the increase in Work to be Done, caused by Scope Change, will lead to an increase in the Working rate, to cope with the increased scope, which will also increase the Perceived Progress, leading to an increase in the Work Really Done. Eventually through this balancing loop, the Work to be Done will decrease.

4.2.2 Time Horizon

Regarding the time horizon of the model, based on the reports received from LevveL, the authors set variable Initial Time to 0 (representing February 2018) which is the start of the project. For the variable Final Time, it is set to 60 months (representing the time needed for the design phase of reinforcing the Afsluitdijk), as shown in Figure 3.

Figure 3. Time Horizon of the model

4.3 Variables Identification

The main variables of the case problem were analyzed and identified before creating the causal loop diagrams through the use of literature review and SD experts. The variables were expanded throughout the modelling process till the model represented the LevveL case as much as possible. Table 1 identified the variables based on their type; endogenous, exogenous, or excluded from the model. The endogenous variables are the dynamic variables involved in the feedback loops of the model, so they allow the researcher to discover the patterns of behavior created by the structure among them and how this behavior may change if the structure was altered. The exogenous variables (outside the model boundary) are the ones whose values are not directly affected by the model. The excluded variables are the ones that are intentionally neglected during the model development. For example, Money was excluded since time will be the unit used to show the impacts and quantify the second order effects in the model. Time can be converted to money, but that is out of the scope of the current model, therefore it was excluded. The reasoning behind categorizing the variables like this is to provide the user with the required explanation that will decide if the model is fulfilling its purpose or not.

Table 1. Model Boundaries

Endogenous	Exogenous	Excluded
Work to be Done	Planned Work to be Done	Money
Old Staff	Planned Work Done	Safety
Working rate	Planned Working Rate	Weather conditions
New Staff	Planned Staff	Resource Availability
Hiring Staff	New Staff Hired per month	
Rework due to Errors	Planned Productivity by One Staff	
Effective Productivity	Scope Change	
Productivity	Obsolescence	

Morale	Obsolescence 2	
Overtime Hours	Planned Approval	
Schedule Pressure	Planned Work Really Done	
Perceived Progress	Planned Progress	
Work to be Done	Planned Hiring	
Working Rate	Planned Dismiss	
Work Done	Months for Approval	
Approval	Months of Training	
Work Really Done	Maximum number of New Staff	
Office Congestion	Scope Change Start	
	Scope Change End	
	Number of cycles	
	Months till next cycle	

Table 2. Model Boundary: Variables Overview

Variables	Description	Type	Units
Planned Work to be Done	The planned number of Work Packages required to finish the New Sluices	Exogenous	Work Package
Planned Working Rate	Planned monthly productivity of one staff multiplied by the planned staff	Endogenous	Work Package/Month
Planned Work Done	Number of completed Work Packages waiting for approval	Exogenous	Work Package
Planned Work Really Done	Number of completed Work Packages	Exogenous	Work Package
Planned Staff	Number of People needed to complete the Planned Work	Exogenous	People (Full time equivalent)
Old Staff	Sum of Planned Staff and newly trained staff	Endogenous	People (Full time equivalent)
New Staff	Number of new People hired after the initial time	Endogenous	People (Full time equivalent)
New Staff Hired per month	Number of People that can be hired in one month	Exogenous	People/Month
Hiring Staff Rate	Hiring staff factor multiplied by staff requested	Endogenous	People/Month
Planned Productivity by One Staff	The expected productivity of one person per month	Exogenous	Work Package/Month
Effective Productivity	Planned Productivity by One Staff multiplied by Productivity	Endogenous	Work Package/Month
Productivity	The multiplication of the influence of overtime, morale, schedule pressure and office congestion	Endogenous	Percentage, 100% means productivity planned
Morale	Motivation of the staff at a particular time	Endogenous	Percentage,

			100% means maximum motivation
Overtime Hours	Extra time spent by the staff	Endogenous	Hours
Schedule Pressure	When the perceived progress is less than the planned progress	Endogenous	Percentage 100% means maximum schedule pressure
Perceived Progress	Number of Work Packages in Work Really Done divided with the sum of number of Work Packages in Work Done, Work to be Done and Work Really Done	Endogenous	Percentage 100& means the project is finished
Scope Change Rate	Rate at which changes are occurring	Exogenous	Work Package/Month
Work to be Done	Number of Work Packages need to be done	Endogenous	Work Package
Working rate	Rate at which Work Packages are completed	Endogenous	Work Package/Month
Work Done	Number of work packages completed before approval	Endogenous	Work Package
Approval rate	Rate at which the work done is approved	Endogenous	Work Package/Month
Work Really Done	Number of work packages completely finished after approval	Endogenous	Work Package
Rework due to Errors	Rate at which Work Packages are rejected on monthly basis, due to Errors	Endogenous	Work Package/Month
Obsolescence	Rate at which Work Packages are rejected on monthly basis, due to not being needed anymore	Endogenous	Work Package/Month
Maximum number of New Staff	The maximum number of new staff that could be hired for the project	Exogenous	People (Full time equivalent)

Scope Change Start	Number of months after Initial Time when the Scope Change is first introduced	Exogenous	Month
Scope Change End	Number of months after Initial Time when the Scope Change ended.	Exogenous	Month
Number of cycles	Number of times that the same change described with Scope Change Input disturbed the initial scope	Exogenous	Dimensionless
Months till next cycle	Number of months between two disturbances described with Number of Cycles	Exogenous	Month

4.4 Formulation of Dynamic Hypothesis

After identifying the variables that will be incorporated in the model, a causal loop diagram (CLD) should be developed to allow better understanding of the system. To do so, causal loops were first created to show the cause-and-effect relationships between the variables.

Starting from the occurrence of the scope change, the number of work packages to be done increases. The increased Work to be Done will lead to Schedule Pressure, since the main objective of both parties is to finish on time and with the least costs. However, the increase of Schedule Pressure leads to increase in Errors and also to decrease in Productivity. The occurrence of both incidents will lead to decrease in the Work Really Done (Reinforcing loop). The project manager will also try to apply some managerial techniques. These managerial techniques are Overtime and Hiring New Staff to substitute for the increased Work Packages that have to be accomplished per month. Overtime will increase the Work Really Done (Balancing loop), but it will also lead to increase in Errors or decrease in Productivity, which will negatively influence the Work Really Done (Reinforcing loop). Through the loops of the dynamic hypothesis, the authors were able to show and identify both scenarios in the model. The other managerial technique is Hiring New Staff with the aim of increasing the number of Work Packages to be accomplished per month. Hiring New Staff will allow more work to be accomplished per month, which will increase the Work Really Done (Balancing loop). But this will also lead to an increase in Office Congestion, which will decrease Productivity and the Work Really Done (Reinforcing loop).

Accordingly, nine causal loops were defined, seven of them are reinforcing loops and the other two are balancing loops as shown in Figure 4. To present the loops in a consistent format, all the loops begin, and end with "Work to be Done".

1. Work to be Done > - Perceived Progress > - Schedule Pressure > + Error > + Work to be Done (Reinforcing Loop - 1)

2. Work to be Done > - Perceived Progress > - Overtime > + Error > + Work to be Done (Reinforcing Loop - 2)

3. Work to be Done > - Morale > + Productivity > +Work Really Done > -Work to be Done (Reinforcing Loop - 3)

4. Work to be Done > - Perceived Progress > - Hire Staff > +Office Congestion>+Errors> + Work to be done (Reinforcing Loop - 4)

5. Work to be Done > -Perceived Progress > - Hire Staff > +Office Congestion> - Productivity > +Work Really Done> -Work to be Done (Reinforcing Loop - 5)

6. Work to be done > - Perceived Progress > - Overtime > -Productivity > +Work really done > - Work to be done (Reinforcing Loop - 6)

7. Work to be done > - Perceived Progress > - Schedule Pressure > -Productivity > + Work really Done > - Work to be done (Reinforcing Loop - 7)

8. Work to be done > - Perceived Progress > - Hire Staff > + Work really Done > - Work to be done (Balancing Loop - 1)

9. Work to be done > - Perceived Progress > - Overtime >+ Work really Done> - Work to be done (Balancing Loop - 2)

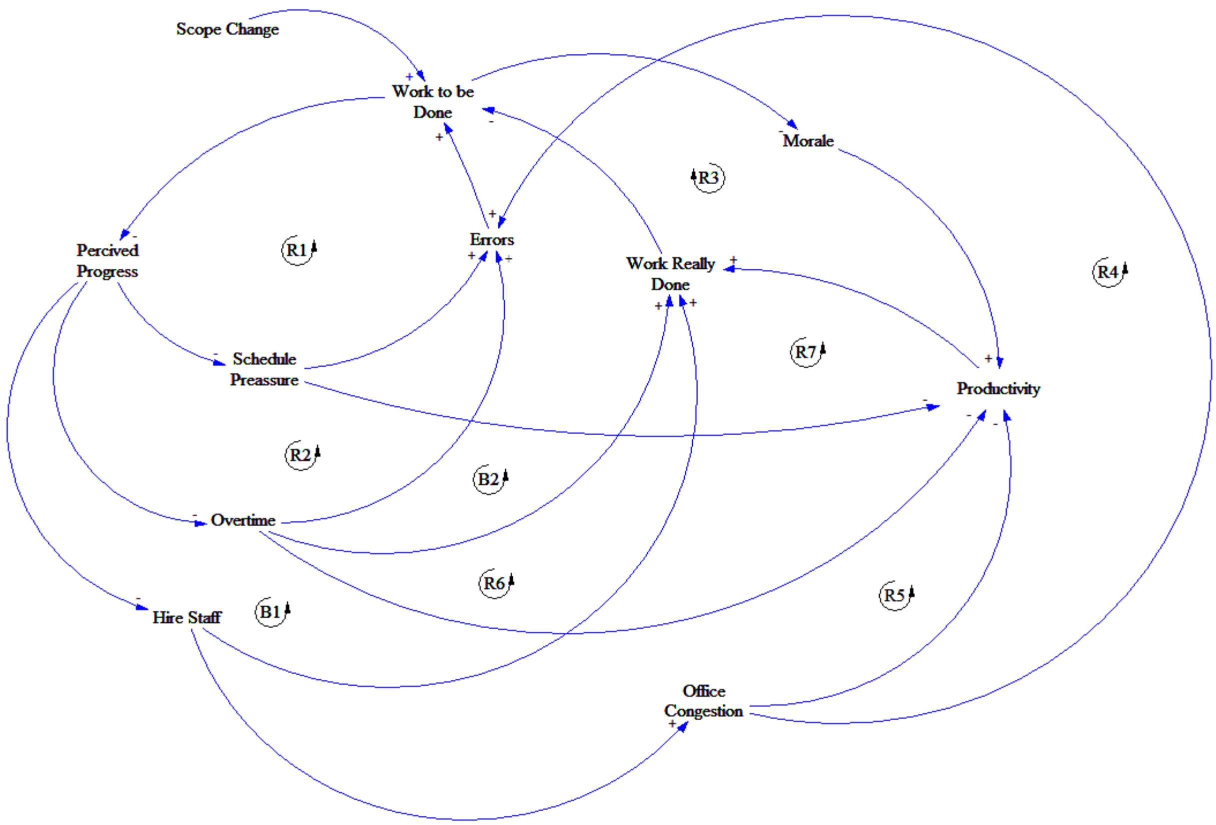


Figure 4. Dynamic Hypothesis

4.5 Model Formulation

Based on the validated models created by Chang et al. (2007), Sterman (2010), Cooper & Lee (2012), Warhoe (2013), a system dynamics model with stock-flow diagram was created. The main issue of the LevveL case is scope change. LevveL case problem is similar to the basic issue of Fluor's case (Cooper & Lee, 2012). Therefore, the initial start of the model was inspired by Fluor's model (Cooper & Lee, 2012). The Fluor model is shown in Figure 5.

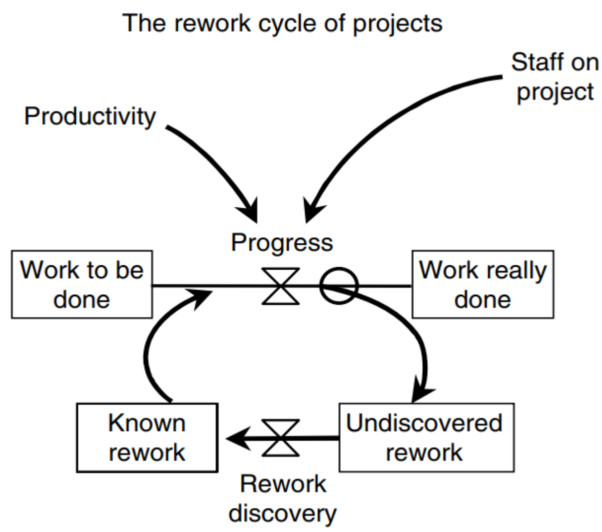


Figure 5. Fluor's starting model (Cooper & Lee, 2012)

When LevveL won the bid, as a contractor they had to do a certain amount of work as specified in the bid documents "Work to be Done". During the simulation, this amount of work will flow through "Work to be Done" towards the "Work Really Done" stock, at a prescribed Working rate depending on LevveL staff productivity. However, the client issued a scope change that added extra Work Packages to the project scope, therefore, it is hypothesized that the Productivity can be impacted. Factors such as Scope Change, Morale, Schedule Pressure, Overtime, Office Congestion, and other create feedback loops that affect the contractor productivity, as well as the working rate flow (Bronner, 1982; Leonard, 1988; Dye, 2011). The complete model with all its parts is developed by the authors and shown in Figure 6 below. It studies the effects of scope change on all these different factors and how these factors are influencing each other, especially the impact on productivity that impacts the working rate. In the next section each of these parts of the model will be separately described.

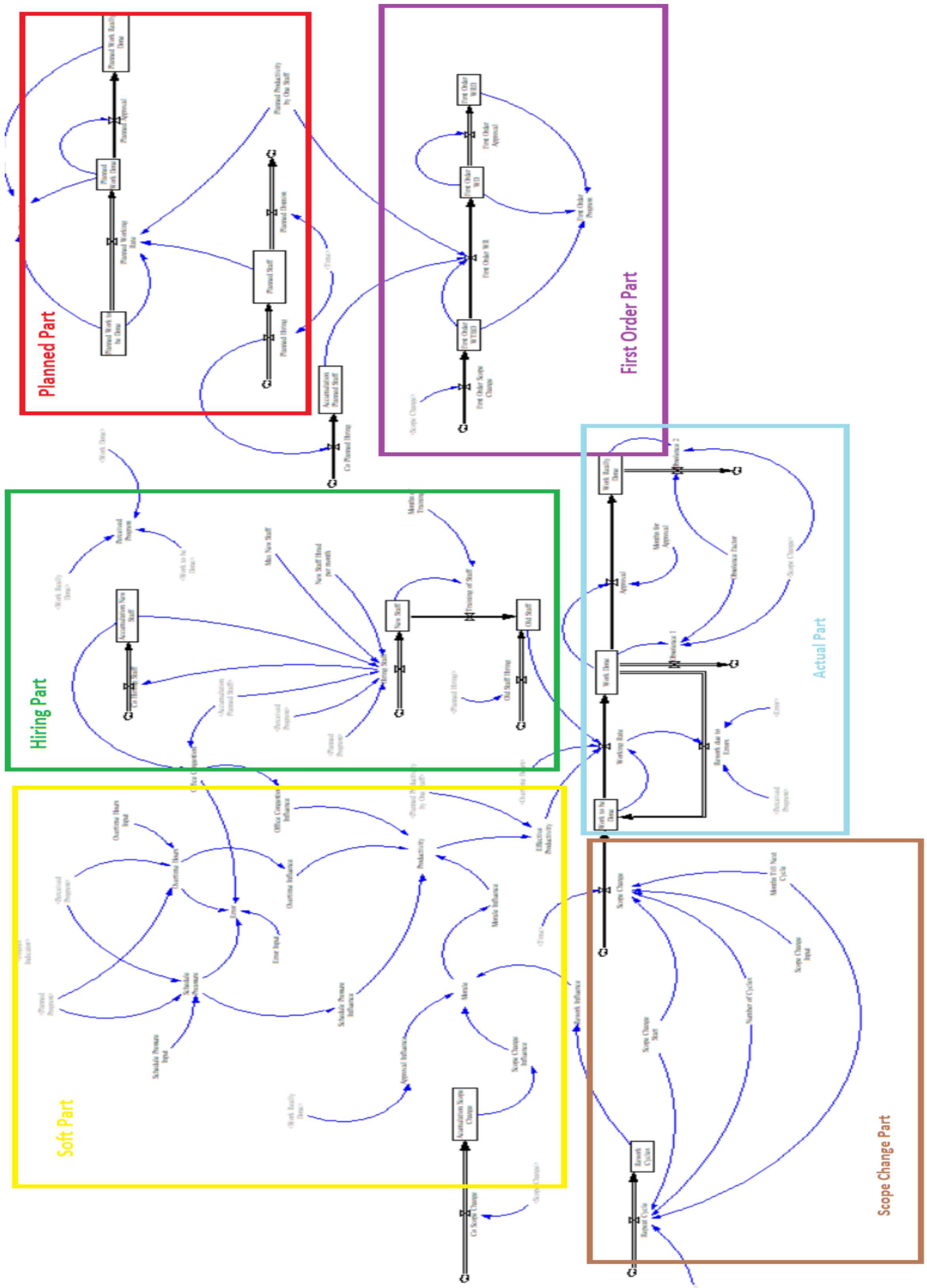


Figure 6. Parts of the model

4.6 Quantitative Model

In this section the process of developing a model from scratch was described. Different parts of the model were introduced one by one, building up to the final model. To ensure that the model is replicable, the authors included all equations used in the model in Appendix C.

Model Parts

4.6.1 Planned part

To be able to compare the actual progress and the planned progress, first the planned model was developed using the inputs from the project reports. The planned scope of the work for New Sluices (Planned Work to Be Done) was assumed to have 100 Work Packages, and the project duration is 21 months according to the reports acquired from the case (LevveL non-disclosed confidential Excel, 2021). From the same report the number of Planned Staff throughout the whole design phase for New Sluices was extracted. This was done by dividing the tendered work hours for each month by the maximum number of work hours per week (40 hours/ week) and the number of weeks in the month (4). This gave the results that 6 people were planned for the first two months of the design phase, then six more people would join them for the next six months. After eight months, six people would leave, leaving the six remaining people to finish the design until the end (21st month). The Planned Staff is shown in Figure 7.

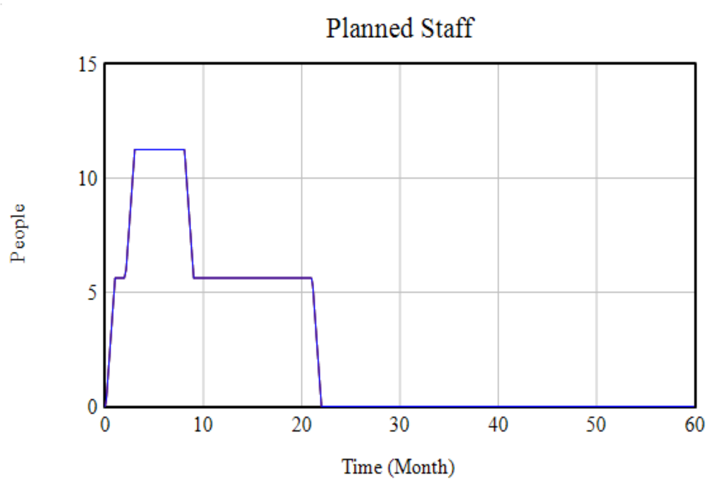


Figure 7. Planned Staff

Based on the number of people to finish the whole scope of designing the New Sluice (100 Work Packages) in a given time (21 Months) the productivity of one person was calculated. The calculation resulted in 0.65 Work Packages per month per person. Planned Approval was modelled as 100%, since this part of the model represents a perfect case, as it was tendered. By simulating and testing this planned model, an observation can be made depending on the value of the Planned Productivity by One Staff, the project would take less or more time to be completed. So, by increasing or decreasing either the Planned Productivity by One Staff or Planned Staff the speed at which the project would be completed can be influenced. This is shown in the planned model in Figure 8.

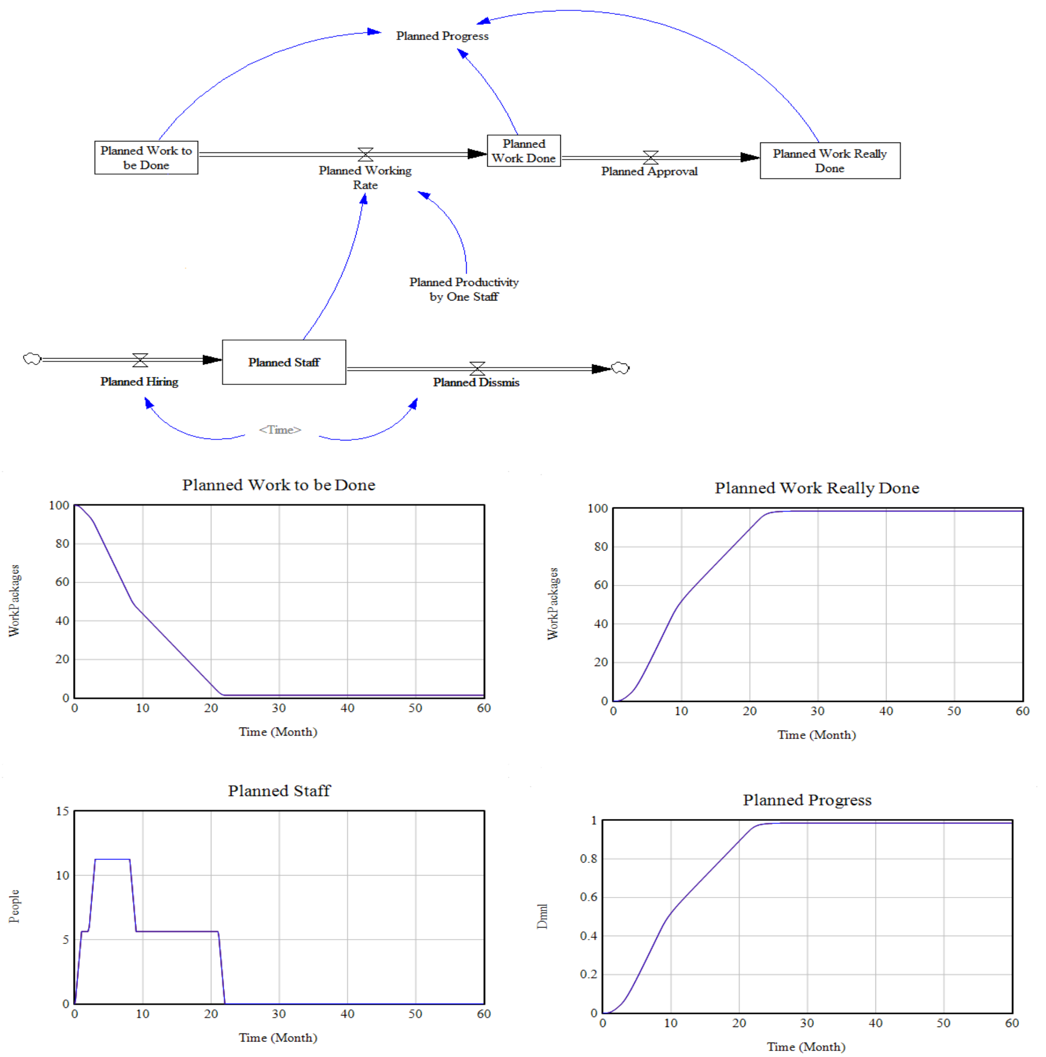


Figure 8. Planned Part of the model

After the simulation, the planned model was completed and ready to be used for developing the actual model. Important is to note that the planned model represents a perfect case, without any influences.

Actual model, before the next part was added to it, looked exactly like the planned model, with the only difference being that the word planned is removed from all variables. This can be seen in Figure 9.

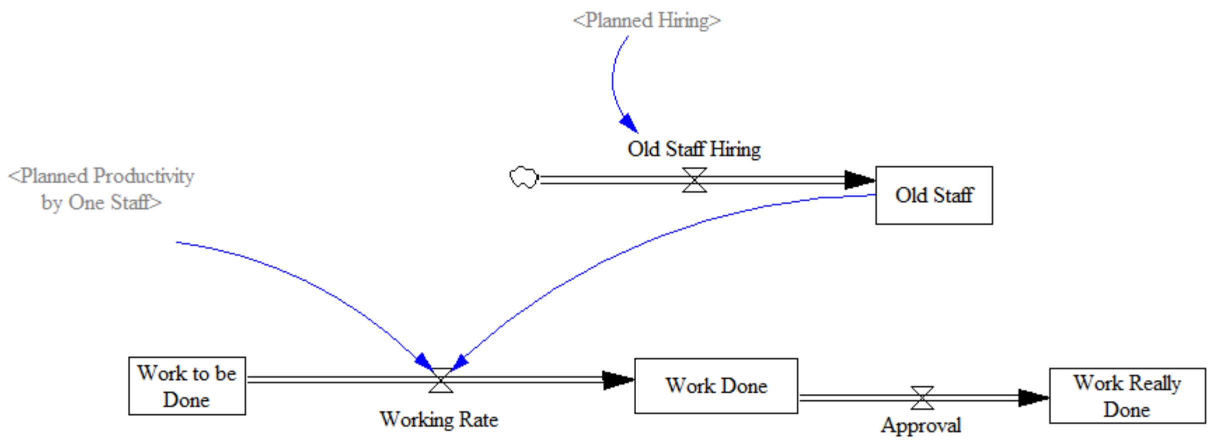


Figure 9. Actual model before parts were added

4.6.2 Scope Change part

With the planned model in place, the next task for authors was to model the disturbance that impacted that planned model. As the model developed was aiming at quantifying second order effects of the scope change, authors modelled the scope change part as an input panel for the final user. This had practical reasons, which allowed easy usage of the model for other objects of the project with different variables. Also, as the project is currently in progress, the exact size of the scope change is still unclear, with experts from the company only having vague assumptions. The Scope Change part is representing the Work Packages that were introduced to the project after the Initial Time, repeating itself in constant intervals, resulting in the same amount of Work Packages becoming obsolete from either Work Done or Work Really Done. This setup leads to the final amount of Work Packages that need to be done for the project completion at 100 Work Packages. The four input variables are shown and described in Table 3.

Table 3. Input variables for Scope Change

Name	Description	Unit
Scope Change Start	Number of months after Initial Time, when the Scope Change is first introduced	Month
Scope Change Input	Number of Work Packages changed in regard to the initial scope (100 Work Packages)	Work Package
Number of Cycles	Number of times that the same change described with Scope Change Input disturbed the initial scope	Dimensionless
Months till Next Cycle	Number of months between two disturbances described with Number of Cycles	Month

Scope Change is an inflow to Work to be Done, as shown in Figure 10, and has a unit of Work Package/Month.

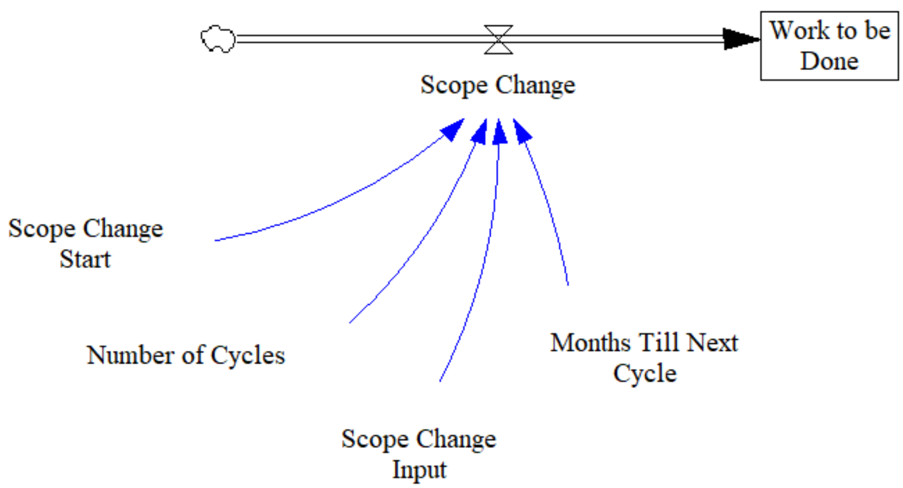


Figure 10. Scope Change part of the model

4.6.3 Soft Variables part

The final part the authors added to the planned model is the soft variables part. Most of these variables are modelled as auxiliary variables, and they are significantly affecting the Working rate. First is the Perceived Progress variable, it is an auxiliary variable showing the current progress and it also gives the opportunity of comparing the progress with the Planned Progress. It has a minimum value of 0 at Initial Time and a maximum value of 1 when the project is finished, while being calculated as shown in formula (1):

$$Perceived\ Progress = \frac{Work\ Really\ Done}{Work\ Done\ +\ Work\ to\ be\ Done\ +\ Work\ Really\ Done} \tag{1}$$

Schedule Pressure is an auxiliary variable that influences the progress of the project. This variable is modelled only to have impact when the Perceived Progress is less than the Planned Progress. The authors found it difficult to determine the exact level of the schedule pressure during the project, because of the different subjective opinions of the experts from LevveL that were consulted. Because of that, the authors modelled the magnitude of this variable as an input. the end user can enter the value between 0 and 100, based on their perception of schedule pressure. That number will be used as an input for the lookup function showing the influence that the Schedule Pressure has on Productivity, with values according to literature (Nepal, 2006), as shown in Figure 11. Values were taken from the graph of complex tasks.

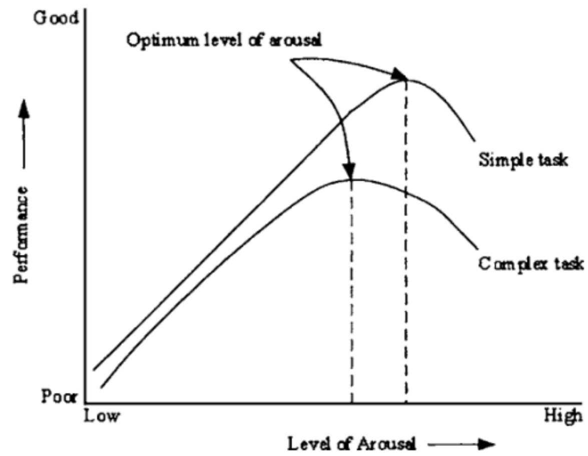


Figure 11. Schedule Pressure Influence (Nepal, 2006)

The next auxiliary variable is the Morale. As literature shows, repetition of the work gradually demotivates the staff (Shaban & Alqotaish, 2017). Experts from LevveL said, through the interviews, that the initial change can be seen as a motivating factor also, because there is a new problem to solve, but that constant repetition of those new problems appearing is a greatly demotivating factor. Another factor they described is motivation gained from the submission and approval of work done. Having all that in mind, authors modelled morale as an effect of Number of Cycles, Scope Change Input and Work Really Done, with the first two representing the influence of scope change, while the third one represents the effects of submission and approval. All of these variables are used as an input for their corresponding lookup functions showing their influences on morale. These influences, Scope Change Influence, Rework Influence and Approval Influence are modelled based on the information received from LevveL experts and are shown in Figures 12, 13 and 14. Finally, the morale is calculated as a sum of those two influences as show in formula (2):

$$Morale = \frac{Rework\ Influence\ +\ Scope\ Change\ Influence}{2} + Approval\ Influence \tag{2}$$

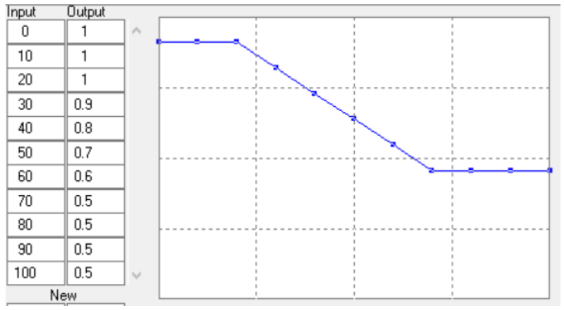


Figure 12. Schedule Pressure Influence (Nepal, 2006)

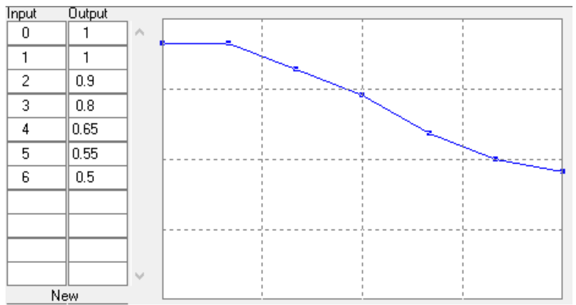


Figure 13. Rework Influence on Morale

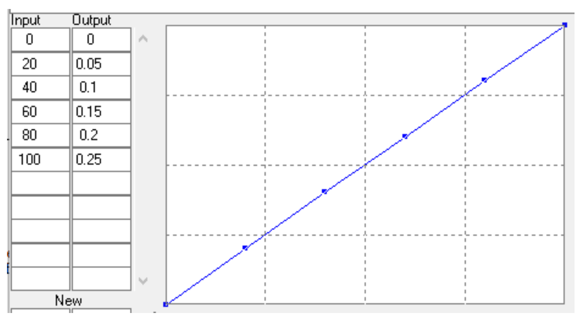


Figure 14. Approval Influence on Morale

Influence that Morale has on Productivity is shown with a lookup function, with values taken from literature (Osho, 2006), as in Figure 15.

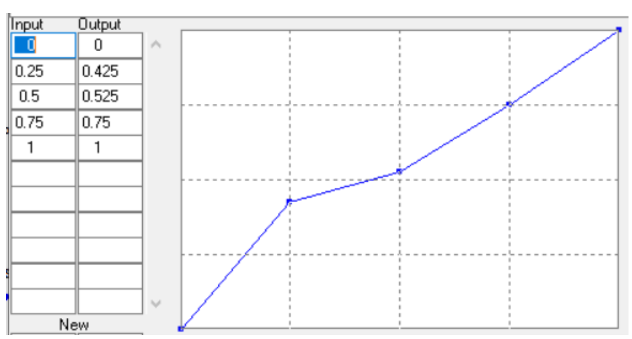


Figure 15. Morale Influence on Productivity (Osho, 2006)

As previously mentioned, hiring more personnel is one of the ways to cope with delayed projects. Authors modelled that as a rate, Hiring Staff, representing the number of new staff LevveL hired per month. It is activated when the Perceived Progress is less than Planned Progress. Planned progress is multiplied by 0.9 to represent the retroactive nature of the decision to hire people, as shown in formula (3). It is also influenced by the New Staff Hired per month, which is modelled as an input variable showing how many persons LevveL can hire per month. Next, Max New Staff was added to this part of the model. It is an input variable giving the user control of the maximum number of New Staff that can be hired, in regard to the Planned Staff.

*IF THEN ELSE(ZIDZ(Accumulation New Staff, Accumulation Planned Staff)<=Max New Staff, IF THEN ELSE(Perceived Progress<0.9*Planned Progress, New Staff Hired per month, 0), 0)*

(3)

*ZIDZ is a function in Vensim software that helps with problems of division with zero, returning zero as a result in those cases.

New Staff is a stock variable showing the number of persons that joined the project later than Initial Time. It has an initial value of 0 and an inflow of Hiring Staff. Based on literature and information gathered through interviews with LevveL experts, New Staff had to go through some training before they become operational and productive when coming to a new project. This time has been modelled as an input variable Months of Training, where users of the model can specify how long the process of training actually lasted. Finally, after completing the training New Staff moves to Old Staff stock, where all the personnel from the beginning of the project is and becomes productive as an Old Staff is. Old Staff Hiring is the Planned Hiring rate for the project from the tender. This part of the model is shown in Figure 16.

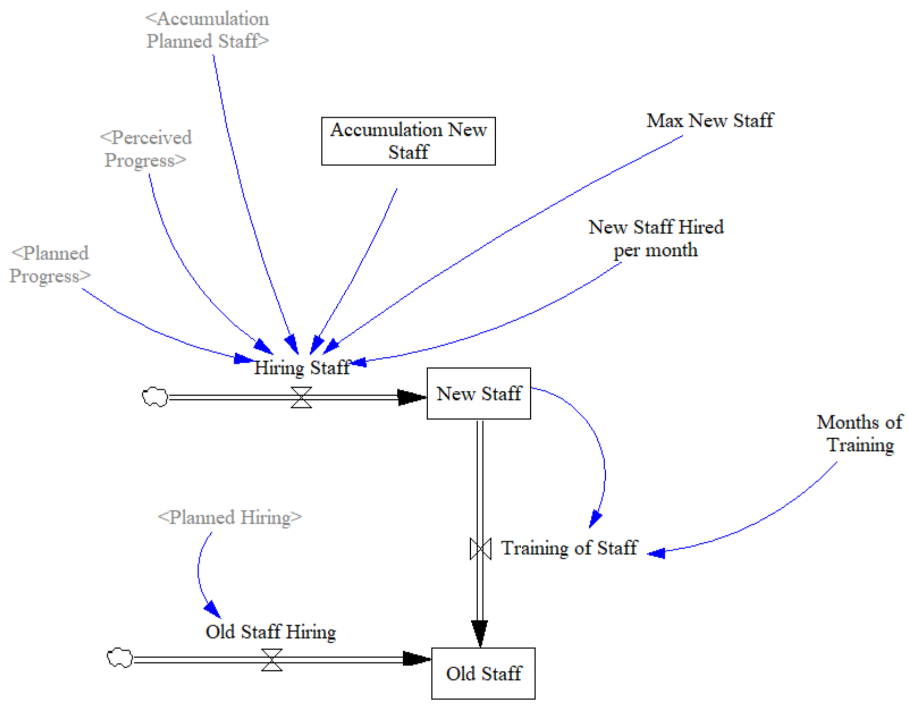


Figure 16. Hiring New Staff

As New Staff now influences the Working rate positively, it also has a negative effect, Office Congestion. Office Congestion is an auxiliary variable. It will have a value between 0 and 1, where 0 presents the optimal case. It represents all the problems of communication and overcrowding in the office, caused by more staff working on the project than planned. It is calculated as shown in formula (4).

$$Office\ Congestion = \frac{New\ Staff}{Planned\ Staff\ +\ New\ Staff} \tag{4}$$

Office Congestion is then used as an input for the lookup function that shows its influence on the Productivity. That influence, Office Congestion Influence is modelled as a lookup function, with values according to literature (Thomas, 1996), as shown in Figure 17.

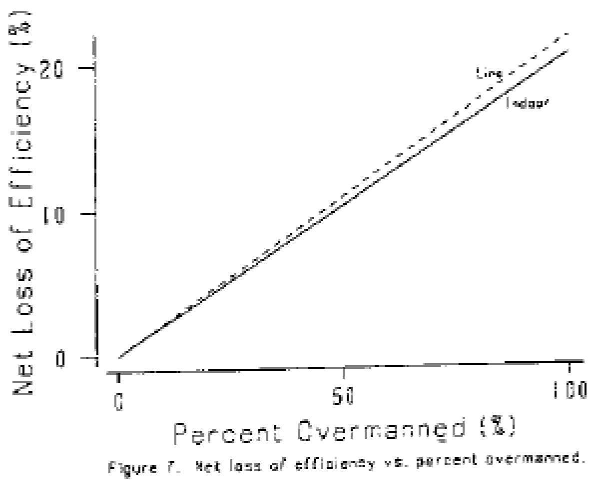


Figure 17. Office Congestion Influence on Productivity (Thomas, 1996)

Overtime is another auxiliary variable included in the model. It is modelled to have a value only when Perceived Progress is less than the Planned Progress. Since the actual data was not recorded, authors modelled the magnitude of this variable as an input, where end users of the model can enter the amount of overtime hours. That value will be the input for the lookup functions showing the influence of Overtime to Productivity. This influence was taken from literature (Hanna, 2005), and is shown in Figure 18. Also, overtime will influence the working rate, as shown in formula 8, because more hours are now devoted to working.

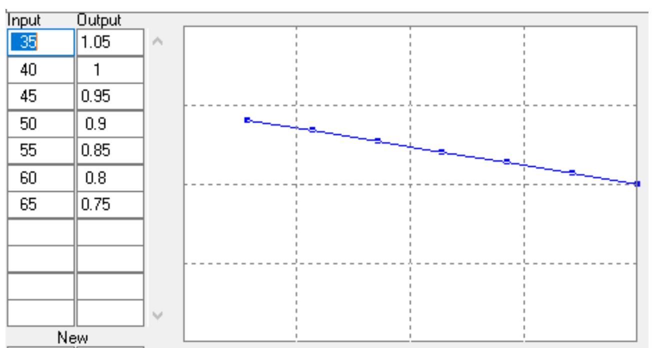


Figure 18. Overtime Influence on Productivity (Hanna, 2005)

Errors is an auxiliary variable, showing the percentage of the Work Done that needs to be redone due to errors. This is done through Rework due to Error rate, connecting Work Done and Work to be Done, as shown in Figure 19. Since it was hard for authors to quantify the percentage of errors, due to subjective answers of the experts from Levvel that were consulted for this part, authors made it an input variable. That variable will have effect when Overtime, Office

Congestion and Schedule Pressure are present, to distinguish those errors from usual errors that would happen not as a cause of scope change. Based on the interviews, authors modelled it to a value between 0 and 20%, where 0 presents the optimal case. Also, for the model to eventually finish, authors assumed that after 99% of the project is complete, no more errors will be made. This is shown in formula (5).

*Rework due to Errors = IF THEN ELSE(Perceived Progress<0.99, Error*Working Rate, 0)*

(5)

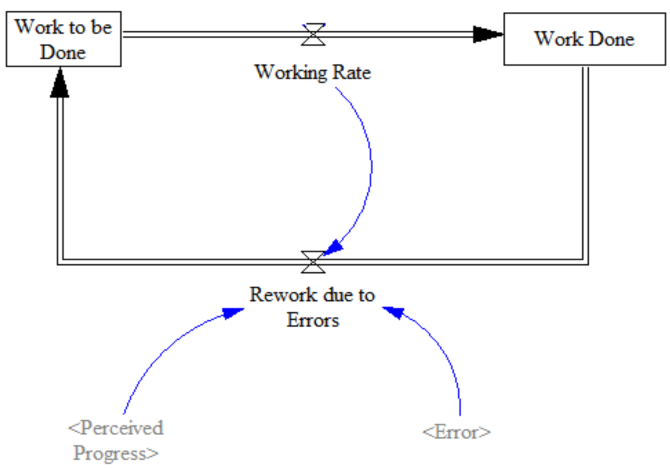


Figure 19. Rework due to Errors

Productivity is an auxiliary variable, and it will have a value between 0 and 1, where 1 presents the optimal case. It is influenced by Moral, Office Congestion, Overtime and Schedule Pressure, through their corresponding influences. It is defined with formula (6).

$$Productivity = Overtime\ Influence * Schedule\ Pressure\ Influence * Morale\ Influence * (1 - Office\ Congestion) \tag{6}$$

Finally, Effective Productivity is introduced to convert Productivity from percentages to Work Packages per month, using the Planned Productivity by One Staff (formula 7). It is then constituting the Working Rate of the model, together with Old Staff and Overtime. It can be observed that if there were people getting trained, the work hours of Old Staff will be decreased by 15%, as shown in formula 8.This represents the time that would be lost on training of the New Staff.

$$Effective\ Productivity = Planned\ Productivity\ by\ One\ Staff * Productivity \tag{7}$$

*Working Rate = MIN(Work to be Done, IF THEN ELSE(Training of Staff>0, 0.85 *Old Staff*(Overtime Hours/40)*Effective Productivity, Old Staff*(Overtime Hours/40)*Effective Productivity))*

(8)

4.6.4 Supporting variables part

In this subsection authors will present pieces of the model that were not discussed in previous subsections but have significant influence for the model.

Months for Approval, is an input variable, introduced by authors to simulate the delayed process of approval of Work Packages. It gives the end user the ability to enter the number of Months that was needed for the approval of Work Packages.

Obsolescence factor is an input variable introduced by authors to simulate the phase in which obsolete Work Packages were identified. It can have a value between 0 and 1. Value 0 would mean that all the Work Packages that became obsolete because of the Scope Change are from Work Done. If the value for Obsolescence factor is set to 0.5, it would mean that half of the Work Packages were from Work Done and half from Work Really Done. Finally, a value of 1, would mean that all Work Packages came from Work Really Done.

Throughout the model several co-flows were created that represent an exact copy of one of the flows already in the model. This process would usually be used when an independent accumulation of some flow is needed for the modelling purposes. The final version of the model is shown in Figure 20 and Figure 21.

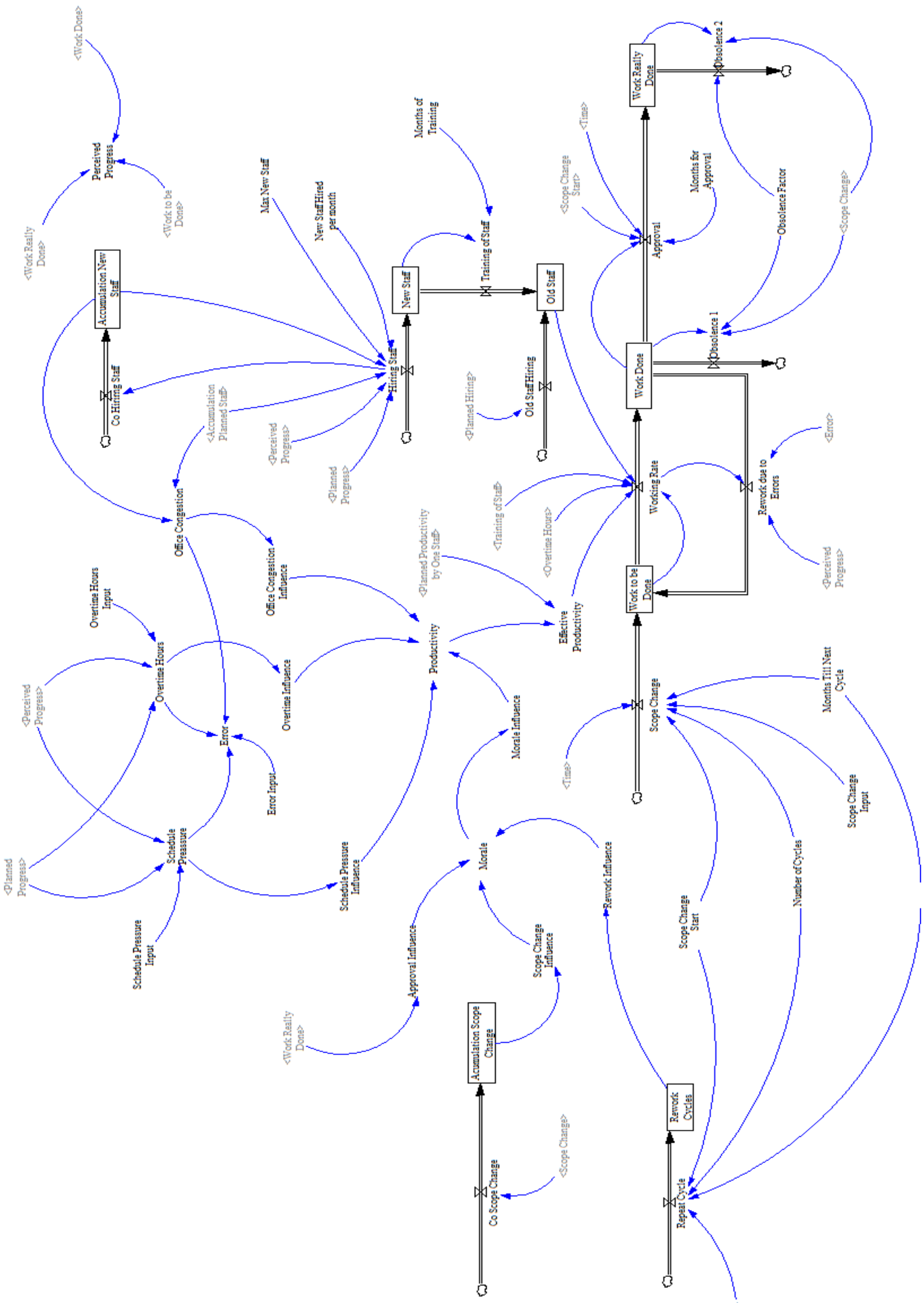


Figure 20. Whole model part 1

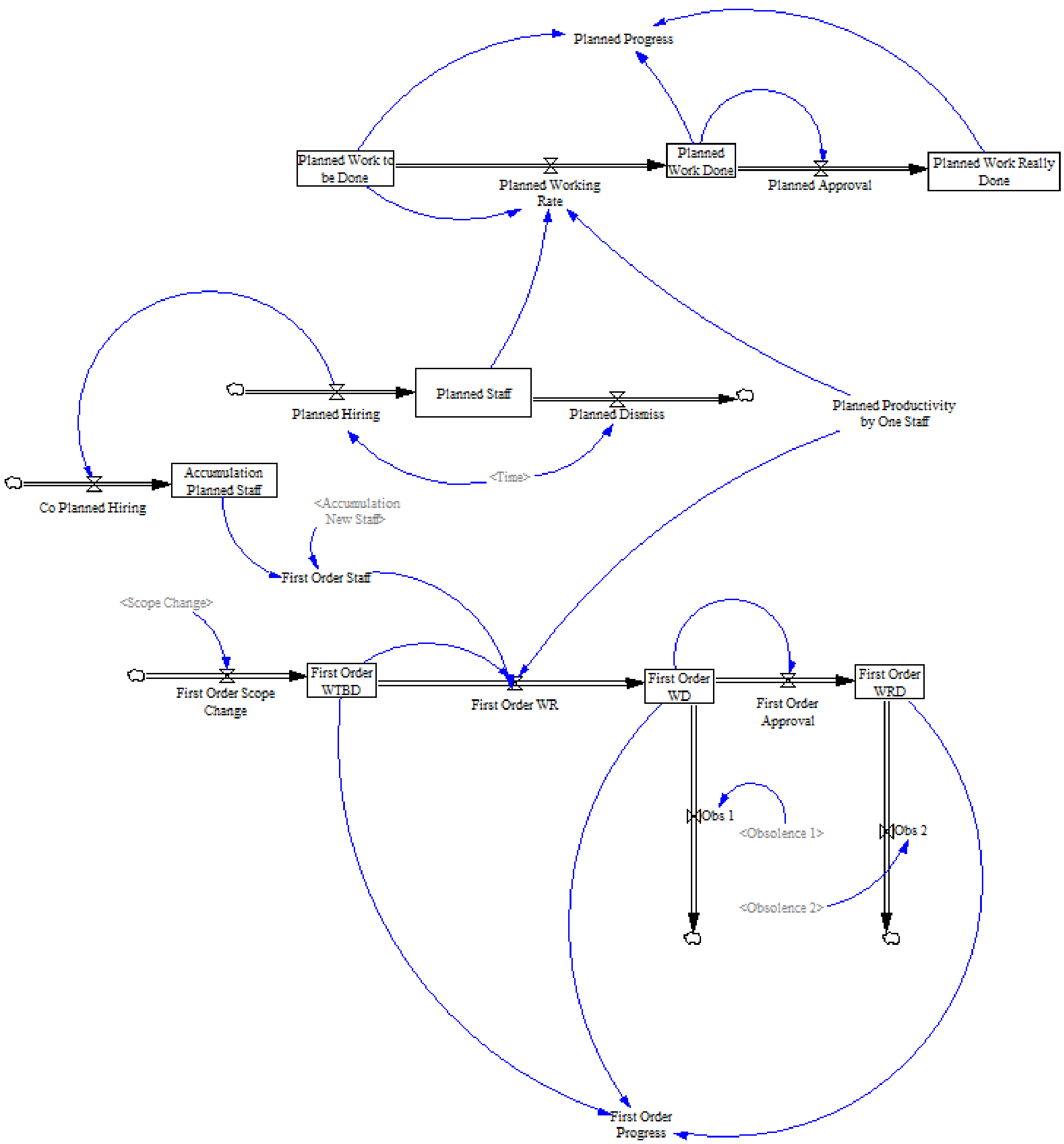


Figure 21. Whole model part 2

4.7 Model Verification

Model verification was a crucial step in the model processing. In this step the final model was analyzed and compared to determine if it was correctly designed based on the initial conceptual model or not. According to Sterman (2000) the model has to undergo structural and behavioural tests in order for the system dynamics model to be verified. Throughout these verification processes, the authors were able to detect the errors, acknowledge the model limitations and test if the model is fit for purpose. This gave the opportunity to the authors to fix the detected errors and improve the model if needed.

4.7.1 **Boundary Adequacy**

There are two questions asked in Sterman's book (2000) for testing the boundary adequacy. The first question is asking if the important concepts for addressing the problem are endogenous to the model. The purpose of the question is to identify if the data input in the model generates output or is the model itself generating the output. This question was answered in Table 1, since all the variables used in the model were identified as Endogenous or Exogenous. The main Endogenous variables were Productivity, Morale, Overtime, Work to be Done and Errors. The main Exogenous variables were Planned Staff, Scope Change Input and Number of Cycles. The second question asked is if the behavior of the model changes significantly when boundary assumptions are relaxed. In the case of the current model, the behavior of the model does change when the boundary assumptions are relaxed. Moreover, when the boundary assumptions are increased or decreased a chain of cause and effect is generated, which will influence other variables in the model. As an example, Work to be Done is considered a boundary assumption; because when Work to be Done is increased, more staff will be hired; the impact of Office Congestion on Errors will be impacted, Productivity will be affected as well as the number of Work Packages really done.

4.7.2 Structure Verification

Structure verification is the second test in the verification process. In this step, Sterman (2000) asked if the model structure is consistent with relevant descriptive knowledge of the system. The causal loop diagram of the second order effects of scope change shown in figure 4 displays linear and nonlinear cause and effect relationships between the model variables. As the scope change is confirmed and inserted in the model, the number of work packages required to be done to finish the project is changed. Also, some of the work packages done might need to be reworked since the scope change affected the structure design. When the perceived progress is less than the planned, the project manager uses two techniques: Overtime and Hiring New Staff. First, increasing the working hours of the staff will lead to Errors, and at some point, will decrease Productivity. Second, Hiring New Staff seems like a positive option, but the more staff hired in the office will increase the Office Congestion. Office Congestion might lead to lower Productivity, which will impact the number of Work Packages really done per month. Moreover, Hiring New Staff impacts Productivity in several ways. For example, the New Staff will need training before they can be as skilled and productive as the Old Staff. Not to mention that the Old Staff has to invest some of their time in training the New staff which will impact their Productivity and the number of Work Packages really done per month.

4.7.3 Dimensional Consistency

For developing the model authors used the “Vensim” software. The software has a built-in function (Units Check) that tests if the model is modelled consistently regarding the units of variables and notifies the modeler if there are any mistakes. In addition, to this tool, authors tested the equations used in building the model, to confirm that indeed it was modelled consistently regarding the units used.

Equation (1)

$$Perceived\ Progress = \frac{Work\ Really\ Done}{Work\ to\ be\ Done + Work\ Done + Work\ Really\ Done}$$

This equation shows the perceived progress of the project in place. It calculates the percentage of the Work Packages in Work Done regarding all the Work Packages in the project. The unit should be in percentage.

$$[Percentage] = \frac{[Work\ Package]}{[Work\ Package]\ +\ [Work\ Package]\ +\ [Work\ package]}$$
$$= \frac{[Work\ package]}{[Work\ package]} =] = [Percentage]$$

So, this equation is dimensionally consistent.

Equation (7)

$$Effective\ Productivity\ =\ Planned\ Productivity\ by\ One\ Staff\ *\ Productivity$$

First equation (7) is checked. This equation is used to convert the Percentages of Productivity, to Work Package/(Month*Persons) of Effective Productivity. This is done by multiplying Productivity with Planned Productivity by One Staff, which has a unit of Work Package/(Month*Persons).

$$\frac{[WorkPackage]}{[Month] * [Persons]} = \frac{[WorkPackage]}{[Month] * [Persons]} * [Percentage]$$

So, this equation is dimensionally consistent.

Equation (8)

*Working Rate = MIN(Work to be Done, IF THEN ELSE(Training of Staff>0, 0.85 *Old Staff*(Overtime Hours/40)*Effective Productivity, Old Staff*(Overtime Hours/40)*Effective Productivity))*

Next, dimensional consistency of the equation (8) is checked. This equation is used to show the amount of Work Packages that can be done in one month. It is calculated as a product of productivity and the amount of people on the project, incorporating the additional work that is done through overtime. The unit should be Work Package/Month.

$$\frac{[Work\ Package]}{[Month]} = \frac{[Work\ Package]}{[Month]*[Persons]} * \frac{[Hours]}{[Hours]} * [Persons]$$
$$= \frac{[Work\ Package]}{[Month]*[Persons]} * [Persons] = \frac{[Work\ Package]}{[Month]}$$

So, this equation is also dimensionally consistent.

4.7.4 Variables Assessment

According to Forrester (1979) both structure and variable verification are interconnected since both tests stem from the same objective that SD models should aim to describe real decision-making processes.

For the variable assessment test Sterman (2000) asked if the variable values were consistent with relevant descriptive and numerical knowledge of the system. All the variable values used for the causal loop, stock and flow diagrams of the model building are consistent with the knowledge of the construction industry. The values of the model variable are derived from the existing project data and literature.

For instance, the managerial techniques are used by project managers to increase the productive staff work hours on a work package. These techniques are overtime and hiring extra staff. These measures are taken to compensate for the delay in the project schedule due to the scope change. These mentioned techniques will increase the productivity of the staff per month, but it does mean that doubling the staff or their working hours will double the output. There is a noticeable loss of productivity with each of these managerial techniques.

Overtime is a direct path to fast-track a project by increasing the man hours through the use of overtime. This technique keeps the original number of workers who are already familiar with the project and working on it. Still, overtime leads to an increase in errors, decrease in productivity. Figure 22. shows the cumulative effect of overtime on productivity and how it varies with the duration that overtime is used.

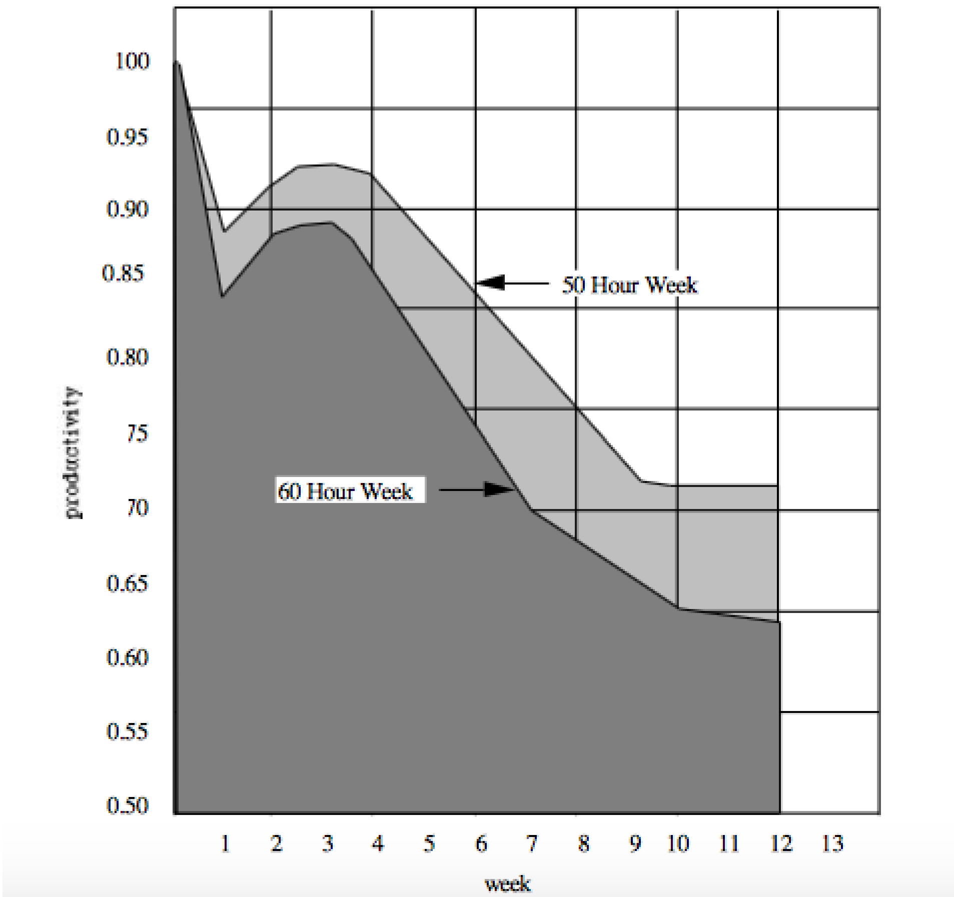


Figure 22. The cumulative effect of overtime on productivity (The Business Roundtable, 1980)

Hiring extra staff refers to increasing the number of staff within the same work package on the project. This technique can increase the work done without the issue of increase in errors that is faced with overtime. However, office congestion impacted by hiring more staff will lead to errors and decrease the staff productivity. Figure 23. shows the loss of productivity due to hiring extra staff.

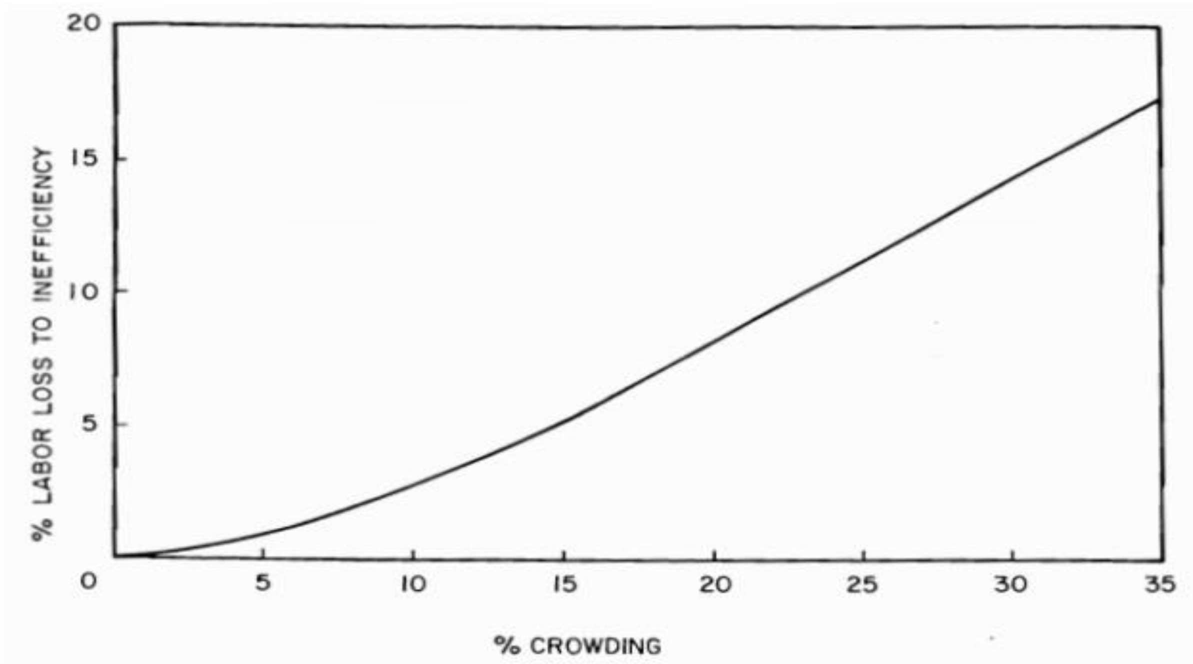


Figure 23. Effect of Crowding on Labor Efficiency (U.S. Army Corps of Engineers, 1979)

Accordingly, it can be concluded that all the variable values used for the causal loop, stock and flow diagrams of the model building are consistent with the knowledge of the construction industry and have counterparts in the real world.

4.7.5 Extreme Condition

“Models should be robust in extreme conditions. Robustness under extreme conditions means the model should behave in a realistic fashion no matter how extreme the inputs or policies imposed on it may be” Sterman (2000).

For the Extreme Condition test, authors simulated the model by giving a minimum or a maximum value to several input variables. The Scope Change part was chosen for this test first as the most important input for the model. The Variable Number of Cycles was set to 0, and the model was simulated. This setup would resemble the case where there is no scope change, and the project should be completed as planned. The model behaved realistically in this test as the simulation forecasted the completion of the project in 21 months.

Next, with Number of Cycles set to 1, to represent the occurrence of the scope change, Scope Change Input set to 100 Work Packages (the initial amount of the project scope), and the scope change start set to 0 the model was simulated. This setup represents the case where the whole project had to be redone fully, but that change was introduced at the beginning of the project, making it a project of its own, without any disturbances, and taking the same time that was initially planned. The model behaved realistically in this test as the simulation forecasted the completion of the project at 21 months.

Moving to the planned part of the model, authors set the Planned Productivity by one Staff to 0. This setup represents the case where staff are not productive at all resulting in the initial scope of the work not to decrease over time. The model behaved realistically in this test as the Work to be Done stayed at 100 Work Packages. Contrary, when the Planned Productivity by One Staff was increased to 1, the model forecasted the completion of the project six months earlier.

Finally, the authors tested the Approval rate, changing the Months for Approval input variable to 12 months. As one year is a very long time for waiting for approval, this would result in the project taking much more time than initially planned. The model behaved realistically in this test as it forecasted the completion of the project at 100 months.

4.7.6 Integration Error

The question asked by Sterman (2000) for this test is if the results are sensitive to the choice of time step or numerical integration method. To initiate the model a numerical integration method and time step should be selected. This selection should give an approximation of the continuous dynamics accurate enough for the model purpose (Sterman, 2000). Still the model should not be sensitive when the numerical integration method or the time step selected is changed.

This test was performed by first changing the time step from 0.0625 to 0.125 and running the model. Then again change the time step to 0.03125 and run the model. The results showed no change for both time steps. Second, an alternate integration method was selected (RK4 Auto) other than the one originally chosen (Euler). Still the results showed no change. Accordingly, it can be confirmed that the current model is not sensitive to the choice of time step or numerical integration method.

4.7.7 Behaviour Reproduction

Behavior reproduction test was performed to compare the results of the model with the real-world data from the project. For the comparison to be accurate, it was decided to compare the perceived progress of the model with the perceived progress of the project. In consultation with experts from LevveL, five key activities for the design of the New Slices were selected to represent the progress of the project. For easier comparison with perceived progress of the model, authors made an average progress from these five activities, shown in Figure 24.

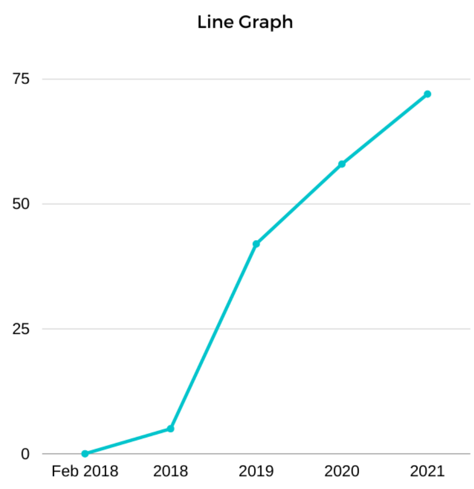


Figure 24. Real-world progress

During this test, it was observed that the data showing progress of the chosen activities, is constantly increasing. This was contradictory to the information authors gathered during the seven months working for the LevveL. After further investigation, it was discovered that LevveL did not increase the scope of the activities during the scope change but was only delaying the end date of the activity. Having this in mind, it can be argued that the model is reproducing the behavior of the real-world project, since both show an S-shaped growth, but because of the limited data from the LevveL, the progress of the project does not show any drops during the whole duration of the project. This inconsistent data was presenting a barrier for this test to be fully completed.

4.7.8 Behaviour Anomaly

In this test, the importance of relationships between variables is examined. This is done by modifying or deleting a relationship and observing what kind of change in behavior it will produce. A common method for searching for behavior anomalies, suggested by Sterman (2000) is loop knockout analysis. This method can be used for elimination of the loops, by setting non-linear relationships to unity for all values. The variable chosen for this test was Morale Influence, representing the relationship between morale and productivity. The lookup function of this variable was changed to have a unified value for any input values. This can be seen in Figure 25.

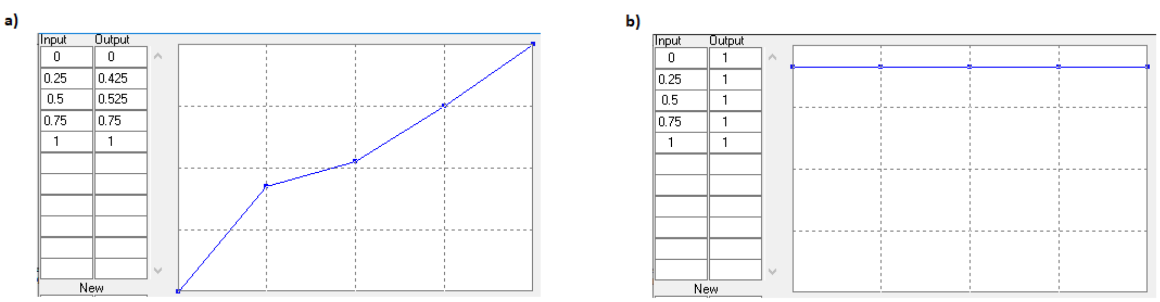


Figure 25. Morale Influence - Anomaly test

With this setup in place, the model was simulated. The influence this change had on productivity can be seen in Figure 26. Since the productivity does not oscillate that much and the drop caused by scope change is quite smaller, it can be concluded that this relationship is indeed important and will have influence on the whole model if changed or deleted.

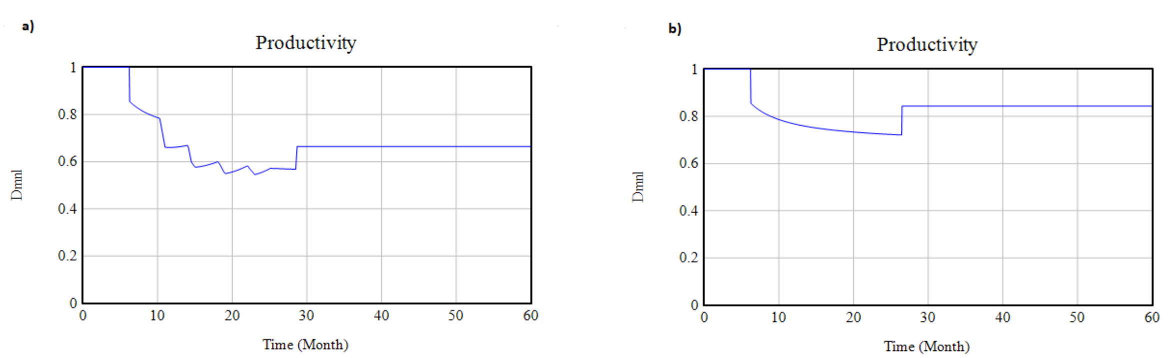


Figure 26. Change in productivity behaviour

4.7.9 Sensitivity Analysis

Since all models are wrong, tests for robustness of the model to uncertainty in assumptions, had to be performed. Sensitivity analysis answers the question "Will conclusions change in ways important to purpose, when assumptions are varied over the plausible range of uncertainty?". Different types of sensitivity exist, while for this case authors focus on observing numerical and behavioral sensitivity of the developed model. Numerical sensitivity exists when a change in assumptions changes the numerical values of the results. All models show numerical sensitivity. Behavior sensitivity exists when a change in assumptions changes the behavior generated by the model. Following Sterman's book (2000), sensitivity analysis was focused on relationships and variables that were suspected to be both highly uncertain and likely to be influential. According to Sterman (2000), variables with no uncertainty do not need to be tested. Likewise, variables that have little effect on the dynamics, do not need to be tested even if its value is highly uncertain.

The first two variables that were tested for sensitivity were Scope Change Influence and Rework Influence. These were chosen since the graph for these influences were drawn as an assumption based on experts' opinions. This made these variables highly uncertain, while the link between morale and productivity made them very influential. For Scope Change Influence, the model was simulated, with the values from the graph first increased for 20%, and then decreased for 20% of chosen values. The impact of this change was observed through changes in the Productivity. While the behavior of Productivity stays the same, it can be concluded that no behavioral sensitivity is present in the developed model. The numerical sensitivity was present, resulting in the values to increase or decrease by around 5%, resulting in productivity to oscillate between 50%-70% in one case, or around 60%-80% in the other one. This can be seen in Figure 27. The same test was done for Rework Influence, and similar results were achieved.

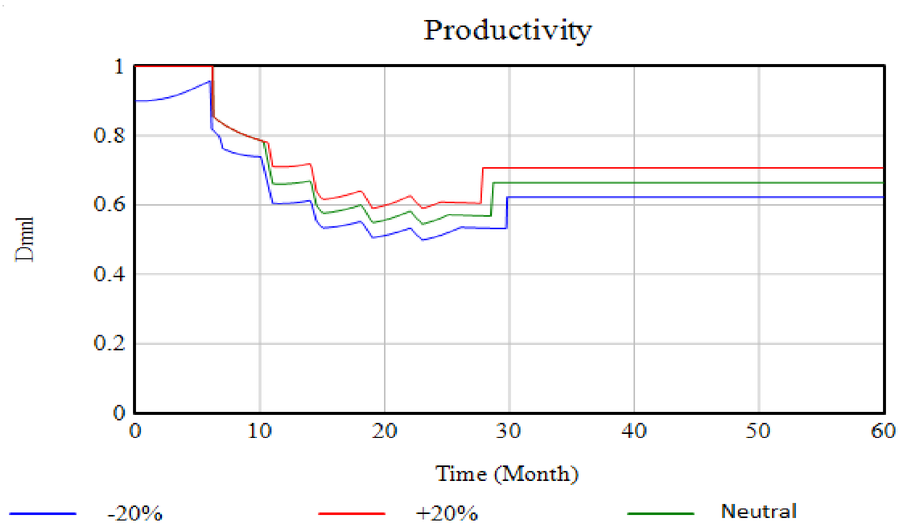


Figure 27. Sensitivity Analysis of Scope Change Influence on Productivity

The third variable that was tested for sensitivity was Approval Influence. It was chosen since the graph for this influence was drawn as an assumption based on experts' opinions. This made this variable highly uncertain, while the link between morale and productivity made it very influential. For Approval Influence, the model was simulated, with the values from the graph first increased for 20%, and then decreased for 20% of chosen values. The impact of this change was observed through changes in the Productivity. While the behavior of Productivity stays the same, it can be concluded that no behavioral sensitivity is present in the developed model. The numerical sensitivity was present, resulting in the values to increase or decrease by around 4%. This can be seen in Figure 28.

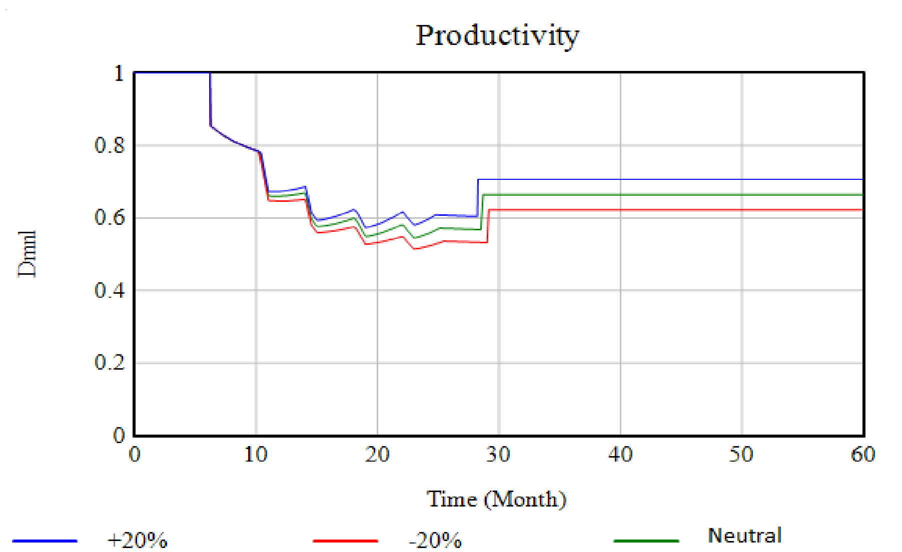


Figure 28. Sensitivity Analysis of Approval Influence on Productivity

The last variable that was tested for sensitivity was Months for Approval. This was chosen since the value of this variable was assumed by authors. This made the variable highly uncertain, while the link between Work Really Done and Perceived Progress made it very influential. For Months of Approval, the model was simulated, with the value of the variable first increased for 30%, and then decreased for 30% of the chosen value. The impact of this change was observed through changes in the Perceived Progress. While the behavior of Perceived Progress stays the same, it can be concluded that no behavioral sensitivity is present in the developed model. The numerical sensitivity was present, resulting in the Perceived Progress to increase or decrease by around 8%. This can be seen in Figure 29.

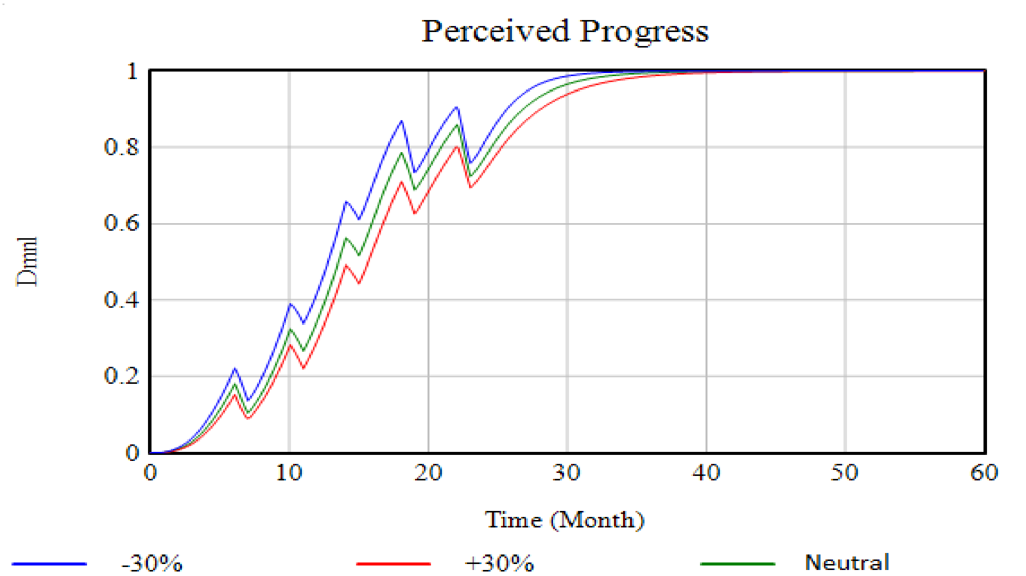


Figure 29. Sensitivity Analysis of Month for Approval to Perceived Progress

After the completion of these tests, it can be concluded that the model behaved like expected during the test, since non-behavioral sensitivity was found, and only numerical sensitivity was shown. The responses of the model regarding numerical changes of values, was consistent and expected, since increase in one variable led to increase of another, and the other way around.

4.8 Conclusion

After the model behaviour and structure were tested, the authors agreed the model is ready to be used. The model provided satisfying results from the tests, keeping its structure and behaviour. The model also kept its forecasting accuracy, even when extreme conditions were assigned to several variables. Finally, all the variables were modelled correctly with their corresponding units, leading to consistency in model usage, regarding both calculation and results.

5 Simulation Results

This chapter presents the setup for simulation and the results it provided. At the end of the chapter, the influence of the first order effects of the scope change was defined, so that second order effects can be quantified.

5.1 Setup

As Vensim software was used for development of the model, before the simulation several settings had to be adjusted in a control panel, as shown in Figure 30.

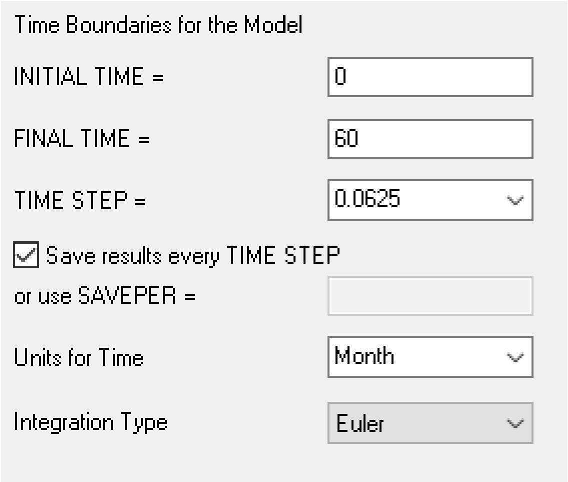


Figure 30.Model Settings in Vensim

Initial time and Final time were explained earlier in Chapter 4, so what is missing to be explained is Time Step. It represents the time after which each new calculation will be made. The smaller Time Step is, the results will be more accurate, but also the hardware used for the simulation will be more loaded. The optimal value for Time Step is chosen by decreasing the Time Step until the model stops changing the behavior between two decreases. For this model variable Time Step was set to 0.0625, while unit for time was chosen to be month and the integration type was set to Euler.

5.2 Input variables

Next authors entered the input values for all the input variables, aiming at representing the project as accurately as possible. The list of input variables and chosen values can be seen in Table 4.

Table 4. Values for input variable

Name of the variable	Value and Unit
Planned Productivity by one Staff	0.65 Work Package/(Month* Person)
Scope Change Start	6 months
Number of Cycles	5
Scope Change Input	30 Work Packages
Months till next Cycle	4 months
Months of Training	2 months
Months for Approval	3 months
Max New Staff	4
New Staff Hired per month	2 persons
Obsolescence factor	0.2
Error input	0.1
Overtime Hours Input	5 hours
Schedule Pressure Input	0.5

These values are the authors best interpretation of the data gathered from the LevveL case, in the process of developing this model. The sources for the data were mainly the Excel tables and PowerPoint presentations that were shared with authors as well as the interviews authors had with experts from the consortium. It should be noted that experts from LevveL check these values and agreed that values proposed in Table 4 represent the project most accurately.

5.3 Simulation

The values proposed by Table 4 complete the model, which was then simulated several times.

5.3.1 Planned part simulation

The planned part of the model, which is modelled based on the tendering documentation, gave us values calculated so that: Planned Work to be Done (100 Work Packages) had to be accomplished by Planned Staff (12 people at peak) with the completion time of Planned Progress (21 Months), resulting in Planned Productivity by One Staff (0.65 Work Packages/(People*Months)). This is shown in Figure 31.

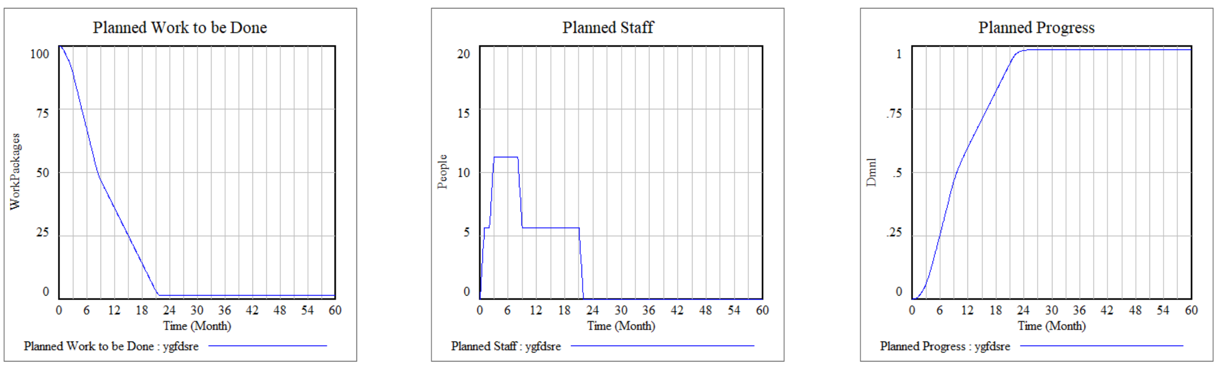


Figure 31. Simulation results of Planned part of the model

5.3.2 Actual part simulation

Same as the planned part of the model, the actual part starts at Initial time equals 0 (February 2018), and has the above-mentioned variables with the same values. After the Time in model has passed the value of Scope Change Start (6 months), Scope Change Input (30 Work Packages) was added to the Work to be Done, on a regular basis every 4 months for next 20 months. Simultaneously, the same amount of Work Packages and in the same intervals is removed from the model through Obsolescence 1, removing unapproved Work Done (80% of Work Packages introduced by Scope Change) and Obsolescence 2, removing approved Work Really Done (20% of Work Packages introduced by Scope Change). This is shown in Figure 32.

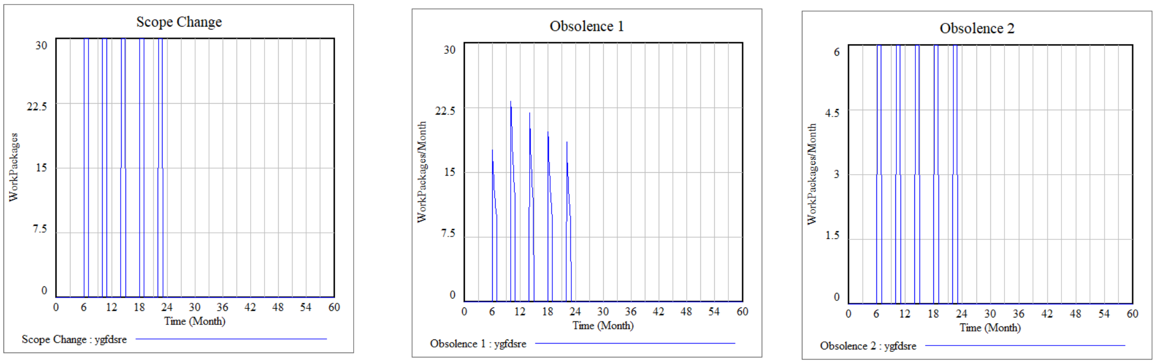


Figure 32. Simulation results of Scope Change part of the model

As a consequence of scope change, in the simulation it can be observed that the Perceived Progress starts falling behind the Planned Progress. In Figure 33, it is shown how the Perceived Progress would look if no measures were introduced. It clearly shows that the project would not be done even in the three times longer duration (60 months) than initially planned. Because of that, different strategies for coping with the consequences of a project falling behind the schedule were introduced, each with its own benefits and drawbacks (Ford & Lyneis, 2019; Bakker, 2020). The Old Staff in the project is put under Schedule Pressure (50%) and starts getting affected by it, while also beginning to work Overtime Hours (45 hours /week). These two variables impacted Productivity and were two out of three triggers for Errors (10%) to start appearing. Meanwhile, the company hires New Staff, by hiring 2 persons per month. The maximum number of New Staff that can be hired is 4 times the Planned Staff, resulting in 48 persons. The New Staff needs to get through training that lasts for 2 Months, in order to become Old Staff and start being productive.

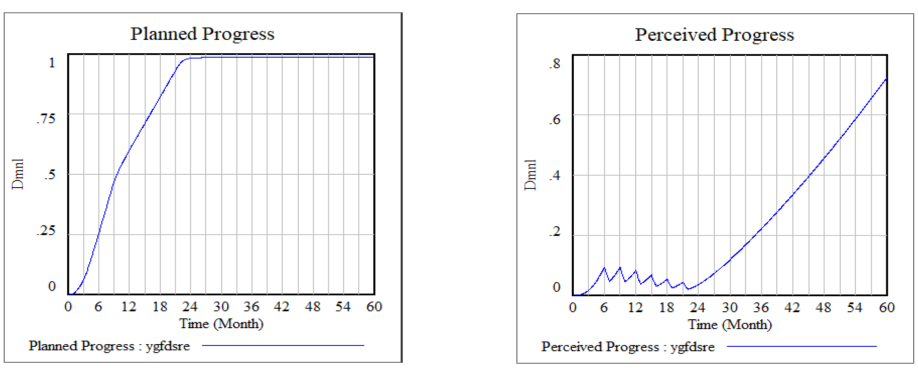


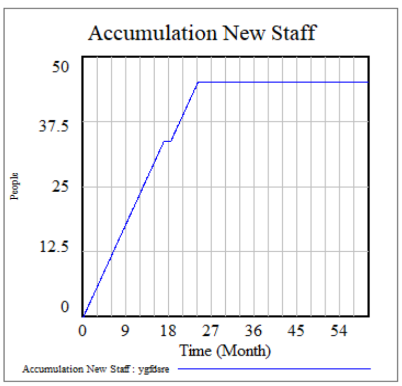
Figure 33. Comparison of Planned and Perceived Progress if no actions were taken

The increase of the people, apart from increasing the Working rate, caused Office Congestion. Office Congestion had a negative impact on the Productivity and was the third trigger for Errors to start appearing.

Finally, as a consequence of the Scope Change, there is the effect on Morale. It is influenced both by the big part of the scope that was changed, Scope Change Input (30 Work Packages, almost 30% of Planned Work to be Done) and the number of iterations (5 cycles).

5.4 Results

The authors looked into the behavior of the model and the results it produced. First, results involving staff were presented. The Accumulation New Staff graph showed that 44 new people were hired in 24 months, while the Old Staff graph showed that total staff was 56 persons, and all of them were fully productive after 30 months. This is shown in Figure 34.



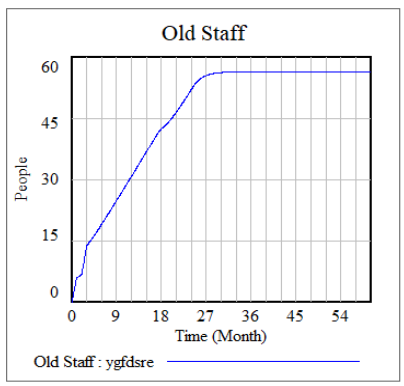


Figure 34. Accumulation of New Staff and Old Staff

Next, results of Morale and Productivity were presented. Morale showed a slight increase in the first 6 months as a consequence of defined scope that had some of the Work Packages already done. When scope change was introduced, Morale dropped instantly, but as the Work Packages that came from that scope change were resolved, morale was again showing slight increase. After 9 months, 3 months after the first appearance, scope change was introduced again, resulting in the second cycle of rework that dropped Morale instantly again. From this point onward, Morale was oscillating between 90% and 70% as a result of scope change repeating itself. Finally, when the scope change ended, Morale stabilized at 80% for the rest of the project. Productivity was following the behavior of the Morale throughout the whole duration of the project, as can be seen in the graphs. Productivity oscillated between 75% and 55% during the period of repetitive scope changes. Finally, when the scope change ended, Productivity stabilized at 66% for the rest of the project. Behavior of Morale and Productivity are shown in Figure 35.

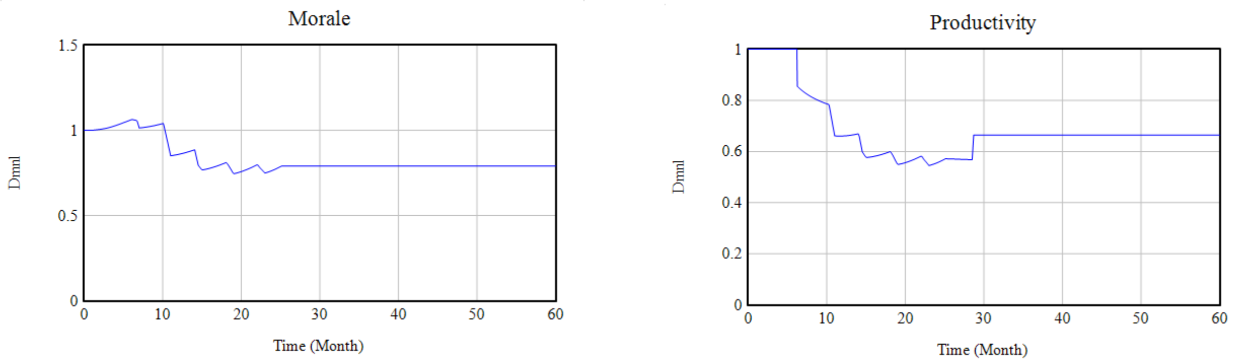


Figure 35. Accumulation of New Staff and Old Staff

Lastly, authors presented the behavior of Perceived Progress, and compared it to Planned Progress. It was observed that the Perceived Progress was following the Planned Progress until the scope change was introduced after 6 months. At that moment, Perceived Progress dropped for around 8%, but continued to steadily increase. This drop of 8% was observed after every new cycle of scope change (every 4 months), as shown in the graph. The Perceived Progress reached 100%, resembling the completion of the project, after 40 months. Compared to the Planned Progress, this represents a 19-month delay, extending the duration of the project to almost double. This is shown in Figure 36.

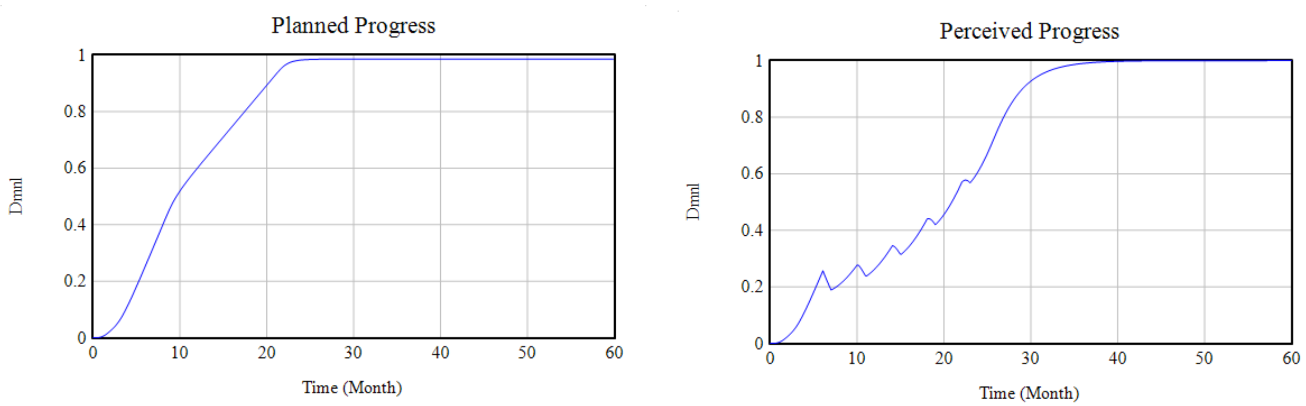


Figure 36. Comparison of Planned and Perceived Progress

5.5 First Order Effects

The extended duration of the project to 40 months was the result of the influence scope change had on the project. But this result consisted of the influence both first order effect and second order effects had on the project. As the goal of this research was to quantify second order effects, authors had to come up with the solution on how to separate them from the total influence of the scope change.

For this, authors had to model a new part of the model that will represent the influence of the first order effects only. This part was modelled as a combination of the planned part and the actual part of the model. Same as in the planned part of the model, this part had stock variables representing Work to be Done and Work Really Done, connected with a Working rate. Opposite to the planned part of the model, this part had an inflow to the Work to be Done, representing the scope change that happened. The values for this inflow will be the same values that scope change had in the actual model.

Apart from scope change, two more variables were added to the actual part of the model to the first order part. Firstly, it was assumed that the Planned Staff would not be able to handle the increased scope of the project alone. This meant that hiring more staff had to take place. But because this part should represent only the first order effects, a new variable had to be created that would represent the total staff on the project but to exclude the training of the staff. A variable named First Order Staff was created, and it represented the sum of Planned Staff and New Staff. This is shown in formula (9).

$$\textit{First Order Staff} = \textit{New Staff} + \textit{Planned Staff} \tag{9}$$

A product of this variable and Planned Productivity by One Staff is resulting in First Order Working rate, as shown in formula (10).

$$\textit{First Order Working Rate} = \textit{First Order Staff} * \textit{Planned Productivity by One Staff} \tag{10}$$

Second variable that was added from the actual part of the model to the first order part was the Obsolescence Factor, which regulates removal of Work Packages from the model. This was done to ensure consistency between the amount of Work Packages in every part of the model, and consequently making values in progress variables more accurate and comparable.

With this setup, authors are simulating that the same amount of Work Packages as in the actual model, have to be done by the same number of persons as in the actual model, but without the influence of the second order effects. The part of the model simulating the first order effect on the project can be seen in Figure 37. The simulation of this part of the model resulted in the project being completed after thirty months. This is shown by the First Order Progress variable, shown in Figure 38.

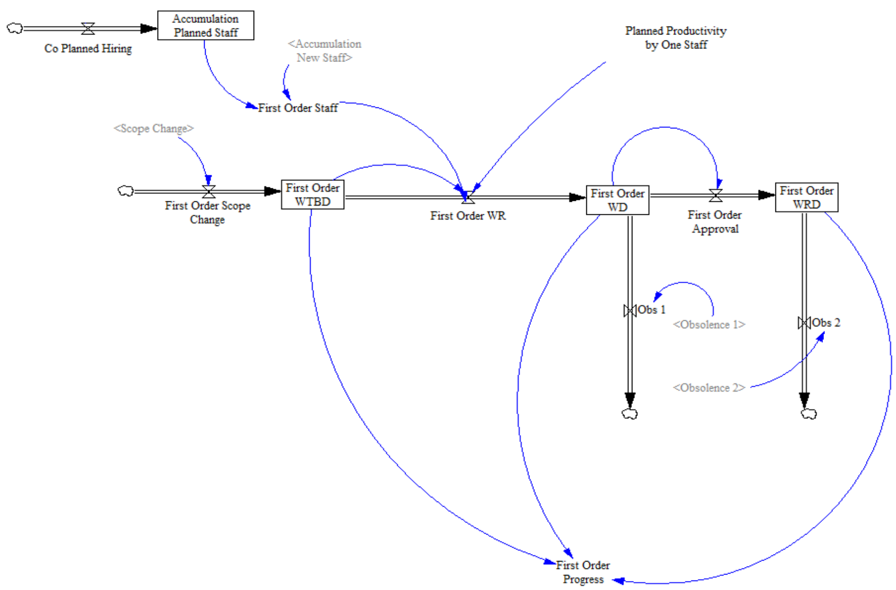


Figure 37. First Order Effects part of the model

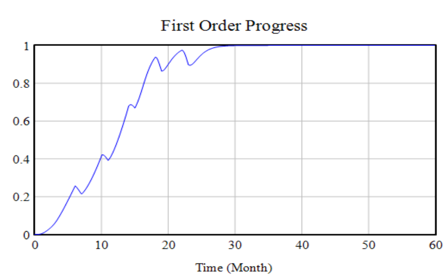


Figure 38. First Order Progress

5.5 Results conclusion

After several simulations, the authors were able to gather the results the model provided. Looking at the outputs of the model, authors made several observations and conclusions. In the beginning, the project progress was following the planned path, until the scope change happened. Scope change increased the initial scope of the project and was the main reason for hiring more staff. Simulation showed that a total of 56 persons were working on the project, which was in line with data authors received from LevveL consortium. Scope Change also influenced the decrease of morale through the project, which in the end resulted in lower productivity. To conclude the influence of the scope change on the project, authors compare progress variables from the model, shown in Figure 39. While the Perceived Progress showed the total influence of the scope change, and resulted in a duration of 40 months, the First Order Progress showed the influence of only first order effects and resulted in a duration of 30 months. Comparing the Perceived Progress to Planned Progress, it was observed that the total influence of the scope change on the project, resulted in doubling the duration, or 100% increase. Comparing the First Order Progress with Planned Progress, it was observed that the influence of first order effects of scope change to the project duration, resulted in 50% increase. To find the influence of second order effect of scope change on project duration, authors compared the time values of the completion of the project from different model parts. Comparing the Perceived Progress and First Order Progress resulted in 10 months difference in completion time. These 10 months represented the influence of second order effects. This result showed that second order effects had almost the same influence on delays as the first order effects in this case. With second order effects adding 10 months of delay, total delays provoked by scope change resulted in 19 months.

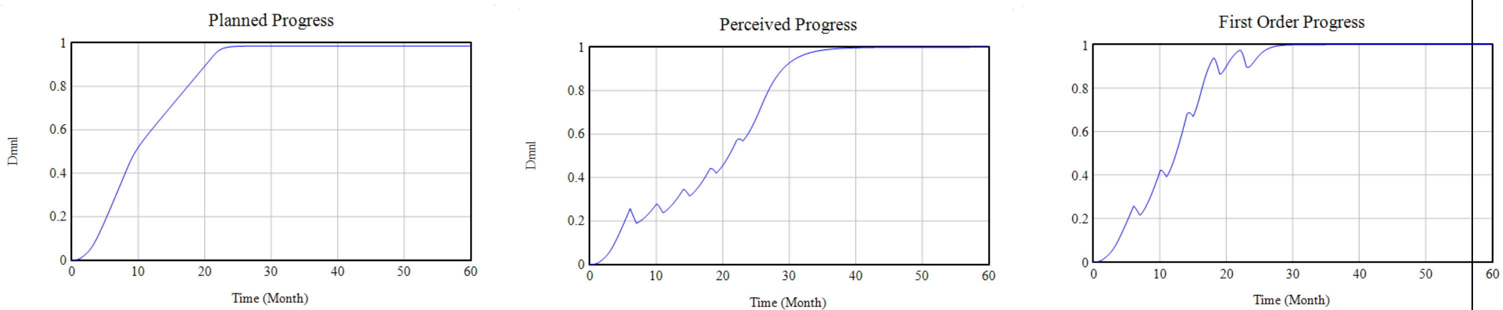


Figure 39. Comparison between progress

6 Impact of Design Uncertainty & Risk Management on Morale

In this chapter, one of the authors (Yassmin Hassan) investigates the impacts of design uncertainty and risk management on the staff morale. Based on the study these two factors will be linked qualitatively into the developed model. First, a literature study was done, followed by structured interviews with the LevveL case experts. Data analysis was carried out with the computer-assisted qualitative data analysis software ATLAS.ti and can be found in Appendix F. Based on the data analysis, the results and discussion were conducted. Finally, the conclusion, limitations and recommendations were developed.

6.1 Introduction

Morale of project teams in the construction industry is a crucial factor when assessing the team performance (Yang, et al., 2010; Dye, 2011; Saldanha, 2018). Morale has a significant impact on the productivity of the team and proven to be one of the key factors affecting the functioning of the team (Dye, 2011; Ahmad, 2014). The current research will investigate the impact of design uncertainties and risk management on team morale using reinforcing the Afsluitdijk project as the case study.

First, uncertainty refers to the absence of information required for the decision that needs to be taken at a point in time (Hassanzadeh, et al., 2011). In construction project management, there is a basic assumption that the construction process is considered to be linear, simple, and sequential (Bertelsen, 2003). However, the construction process is a dynamic complicated process that interacts with varieties of uncertainties (Wood & Ashton , 2009). Owner driven scope change is the greatest source of uncertainty (Ranasinghe, et al., 2021). Uncertainty highly affects the individuals working on the project. For the staff, uncertainty creates stress which leads to lack of control, and feelings of helplessness and mental problems, which highly impact the staff morale. (Dubrin, et al., 2001). Based on this statement, in this chapter the author will elaborate on the impact of uncertainty on the staff morale.

The second factor to be investigated for impacting the staff morale is risk management. Risk is defined as an uncertain event or set of circumstances that occurred that will have an effect on the achievement of the project's objectives (Ranasinghe, et al., 2021). The construction industry suffers from risks in the projects (Flanagan & Norman, 1993; Christodoulou, 2021). When these risks are insufficiently addressed or managed that lead to poor performance, cost overruns and time delays (Thompson & Perry, 1992; Christodoulou, 2021). Thus, risk management is an essential step for delivering a successful project, since risks are present through the whole project cycle (Gerkensmeier, et al., 2018; Christodoulou, 2021). Poor risk management from the early stage of the project might lead to the recurring of these risks in later stages of the project. Poor risk management results in wrong decisions leading to bad relationships with the client, financial loss, and project delays (Ferede, et al., 2020). When the staff is exposed to continuous project delays, they lose motivation to work on the project. Moreover, the more the financial losses the project faces, the more the staff loses trust and commitment to the organization.(Ferede, et al., 2020) Thus, it's important to incorporate risk management as one of the factors that can impact the staff morale.

The influence of design uncertainties and risk management on morale is best to be investigated under real world conditions. Therefore, this research will request participation from a real-world organization and propose collaboration to study the impact of design uncertainty and risk management on morale. The data will be collected through interviews and literature. In this chapter the author will discuss the impact of risk management during the design stage on the staff morale based on interviews with the two main risk managers of the LevveL case. Based on the results both factors will be incorporated in the developed main research model.

6.2 Research Design

In this section the design of the research is described

6.2.1 Research Objectives

The objective of this individual research is to first investigate the impacts of design uncertainty and risk management on the staff morale. Next, the research will explore solutions that could have been done to overcome the loss of morale due to the scope change.

6.2.2 Individual Research Questions

1- How was morale impacted by design uncertainties and risk management?
2- What could have been done to overcome the loss of morale?

6.2.3 Research Methodology

The current study is qualitative research; in which two sources of information for data gathering were used. First, a desk research strategy in which literature study was conducted regarding the impact of design uncertainty and risk management on the staff morale. According to Aitchson (1998) literature review allows the researcher to realize what was done regarding the investigated problem to avoid the occurrence of duplication. Literature review allows identification of gaps in the studied topic as well as a discovery of the connection and contradiction found in previous studies (Bless, 2000). Through this literature study the author was able to formulate the interview questions.

The second source of information comprises interviews with experts from the LevveL case. Interviews were selected as a data gathering method, since according to Ely et al (1994) "qualitative researchers want those who are studied to speak for themselves, to provide their perspectives in words and other actions." Moreover, interviews are useful when specific data is needed in a short space of time and when general oversight of people's thought is required (Welman, 2001). The aim of the interviews is to get the perspective of the experts who have experienced the impact of scope change on the project. The researcher conducted seven interviews that can be found in Appendix F. Two of the interviews were held with two risk managers who are working on the project and were able to reflect their experiences in the project before and after the scope change. The other five interviews were conducted with experts from the design team of the New Sluices. The focus of the five interviews was on the impact of uncertainty resulting from the scope change on the staff morale. The seven interviews were conducted online, and they were anonymous to encourage the experts to give their full opinion. The interviews first addressed general structured questions related to the research questions, and then moved towards a more dynamic dialogue in which the experts shared their personal experiences on the project. The protocol of the interviews can be found in Appendix E.

6.3 Literature review

6.3.1 **Morale**

Morale of the staff has been taking an abundant attention in many industries, and several researches have shown the impact of morale on the staff productivity (Derek et al., 2002; Alam, et al., 2012). In the construction industry, morale plays a significant role in the success and outcome of the product as well as the company (U.S. Bureau of Labor Statistics, 2004). Since the product delivered is highly focused on the quality which is susceptible to the skill of laborers and supervisors. Therefore, low morale can highly impact the project performance (U.S. Bureau of Labor Statistics, 2004). Studies have also shown that the company's success is directly linked to the employee satisfaction, and that the higher the satisfaction of the employee, the less the occurrence of turnover and absenteeism (Maloney, & McFillen, 1986; Freeman, 2005; Alam, et al., 2012). Other studies focused on the factors impacting morale. Uncertain business conditions are found to be one of the factors impacting staff morale (Shaban, et al., 2017); due to human averseness towards uncertainty (Saldenha, 2017).

6.3.2 **Design uncertainties**

Uncertainty is always expected to be present in the design phase, however it turns into a problem when it increases to a level that affects the behaviour or performance of the design team and prevents them from achieving their goal (Ranasinghe, et al., 2021). Uncertainty exposes the staff to high stress, which can lead to feelings of helplessness, lack of control, physical and mental health problems (Dubrin, et al., 2001). Uncertainty also increases staff cynicism, which leads to lower organizational commitment, lower job satisfaction, and lower motivation to work hard

(Dubrin, et al., 2001). Accordingly, it could be shown that all the mentioned causes of uncertainty are the effects of low staff morale.

6.3.3 Risk Management

Risk management is another factor that can affect the staff morale. Risk management is an essential aspect for project success. Since risks exist throughout the project duration, it's crucial to always update the risks and incorporate the new ones and eliminate the identified ones (Munier, 2016; Mantzouka, 2019. Construction projects are known to be permanently exposed to high risks; therefore, risk management has been given substantial research through the years (Serpell et al., 2015; Mantzouka, 2019). Still, there are various deficiencies in the risk management that impact the effectiveness of the project. Insufficient experience and inadequate competence are two of the core deficiencies discussed in several research studies (Serpella et al., 2014; Mantzouka, 2019). Insufficient experience could lead to poor decisions or ineffective strategies that hinder the project success (Tah & Carr, 2001; Akintoye & MacLeod,1997). Not to mention that the higher the complexity of the project the higher the impact of the risk (Zwikael & Ahn, 2011). Another deficiency in risk management is the poor communication between the top management and the project team. When the top management avoids hearing the bad news from the project team and when the project team avoids creating a pessimistic atmosphere (Bhoola et al., 2014). Poor risk management leads to project delays, financial losses, and client distrust (Ferede, et al., 2020). The consequences of poor risk management lead to loss of staff morale. When the project is continuously delayed and the poor management decisions fail; the staff lose trust in the organization's capabilities and lose interest in the methods they are instructed to follow (Ferede et al., 2020). This leads to lower motivation, poor quality, low productivity, and eventually the tendency to leave the project.

6.3.4 Conclusion

Based on the literature review, it was found that morale highly impacts the staff productivity and plays an important factor in construction projects' success. The findings indicated that design uncertainties and poor risk management are two factors that result in lowering the staff morale.

To investigate the findings of the literature review and compare it to the project case, seven interviews were held with the case experts to reflect their experiences and opinions.

6.4 Results

First, the results of the impact of uncertainties on the staff morale will be addressed. Secondly, the interviews' results regarding the impact of risk management on the staff morale will be tackled. The interviews were held to explore the current case further and to identify the problems faced and the suggested alternatives by the interviewees. In total seven interviews were conducted in this phase. The interview protocol is shown in Appendix E. Data analysis was carried out with the computer-assisted qualitative data analysis software ATLAS.ti. First, all transcriptions were uploaded to ATLAS.ti and each of them was read through again. The segments that were also found in literature or were mentioned by more than one expert were marked with the quotation tool. Each quotation was then renamed or given a comment so that later the data could be retrieved and reviewed easily. Second, the quotations were openly coded, and an extensive number of codes were generated. Third, the network tool was used to establish connections of the quotations. In this Chapter the author will focus on the main results of the interviews. All the interview's findings are summarized and added in Appendix F.

6.4.1 Design uncertainty Interviews' results

To address the impact of design uncertainties on the staff morale, the author interviewed 5 experts from the design team of the new sluice. Two experts from the design team worked on the project before and after the scope change and the other three experts only worked on the project after the scope change. For easier reading the author will refer to the experts who attended before and after the scope change as **group A**, and the experts who attended only after the scope change **group B**.

All the experts have at least five years of experience in the construction field. First when the experts were asked about the definition of uncertainties, all of the experts' answers related uncertainties to not knowing the goal or the result of their task in the future. Secondly, when asked if they experienced design uncertainties while working on the project, all the interviewees said yes, but for different reasons. Group A experienced uncertainty of identifying the end goal of their work, "The goal was not clear anymore". However, group B faced uncertainty in what is expected from them, since their tasks were not clear for them. When experts were asked about the effect of design uncertainty on them, it was noticed that group A suffered from rework and the feeling that their work is not efficient anymore. For group B, they described their experience as interesting and challenging, and the only problem of uncertainty is not knowing the level of details in delivering their tasks. An interesting example mentioned by one of the experts in group B "The biggest problem is when the supervisors are also differing, so one person says do it that way and the other person says no, you have to do it the other way".

For the third question, experts were asked if design uncertainty impacted their motivation. Group A confirmed that design uncertainty negatively impacted their motivation due to the amount of rework. As a result, they were not looking forward to doing their work anymore. Also, they explained that the feeling of never reaching the end goal of the task during the scope change was quite demotivating. On the contrary, Group B explained that they were motivated since the case seems like a new challenge. One expert from group B mentioned that design uncertainty does not impact his motivation.

When experts were asked if design uncertainty impacted their team, group A explained that rework due to scope changes caused a lot of frustration between the team. This is because the team had to work on adjusting the same documents for almost two years. For group B, they didn't notice any loss of motivation in the team. One expert from group B claimed that design uncertainty impacts the designers "It's difficult for the designers to say I don't know because the designer wants to have 100% certainty".

On the other hand, when experts were asked what could have been done better to overcome the loss morale. Group A suggested that it would have been better to send everyone home till the scope change problem is clear, instead of having them in the office without understanding or knowing what to do. Group A also recommended that more openness about the problem within the team would have decreased the uncertainty about their work. It was mentioned that during the scope change period some designers had to work on the redesign in a separate room. Such an aspect triggered the curiosity of the rest of the team, and led to more questions, gossip, and confusions within the team. Other suggestions that were raised during the interviews were better communication, a strict schedule, and well explained detailed tasks for the staff. Finally, an intriguing point that was brought up by most experts in the interviews was the importance of the design manager role. The experts compared the old and new design managers and highlighted that a good design manager is one who knows how to reduce the uncertainty. A good design manager is someone who knows how to lead the team, allow them to focus on their tasks and assure them that he/she will handle these uncertainties. The design manager should not only be focusing on the process, but also on the project's technical aspects, which turns positively on the project progress (Yang, et. al, 2010).

6.4.2 Risk management Interview results

To tackle the impact of risk management on the staff morale, the author interviewed two risk managers of the Afsluitdijk project. The first expert worked as a senior risk manager in an oil and gas company for 10 years and joined the Afsluitdijk project in 2020. The second expert worked for 15 years in real estate development, started working as a risk manager in 2016 and joined the Afsluitdijk project in 2018. The two experts were asked to define risk from their perspectives. The experts defined risk as any uncertain event that has cause and effect and could threaten the project objectives, which are scope, schedule, and cost (Serpell et al., 2015; Mantzouka, 2019).

Second, the experts were asked about the impact of scope change on risks. Expert 2 mentioned that the project parts that were not included in the scope change were also affected which increased the project risks. Expert 1 explained that construction companies underestimate the costs; because they focus only on calculating the technical costs and forget to include the overhead costs. "If you look at the schedule delay of one year, you can see how much the direct technical costs occurred in the project. Then, there are also the costs of the organizational level such as your staff, your office, your project controls, and human resources. All your overheads stayed in the project for one year longer. We estimated 50000 euros that we burn a month for the indirect costs".

Third, the experts were asked to highlight the main types of risks that they faced in the project. The experts identified three main types of risks. First, the lack of proper project control and a proper schedule which impact the costs. Second is the political risk; the challenge of getting the permits on time, which impacts the project schedule. The third one is the organizational risk, since the tendered hours required for the tasks were underestimated. This is because the time needed to manage and communicate with such a large staff in this complex project is underestimated, leading to delays, and impacting the risks.

Then, the experts were asked about the impact of the risks on the staff morale. The experts explained that the staff motivation was tremendously impacted by the risks resulting from the scope change. They clarified that a lot of work had to be re-done after the scope change, which led the staff to stress, confusion, and continuous restlessness. Both experts confirmed that many of the staff left the project due to the high stress and workload. Expert 1 mentioned that some people were not experienced or competent enough to be seniors; therefore, they were not able to handle such a huge stress and pressure (Serpella et al., 2014; Mantzouka, 2019).

Subsequently, the experts were asked what could have been done better to reduce these risks. Both experts suggested stopping the project to overlook and investigate the impacts of the scope change, then make the decision to continue or not. Expert 1 recommended having managers who are willing to discuss the problems instead of ones who block the staff away to avoid hearing the bad news.

Finally, the experts explained that since they joined the project, the risks were divided into three divisions; the disciplines, financial risks, and planning risks " Risk management was in process management. Planning was also in process management, but planning was separated from risk management. Then we have finance as also a separate part." Expert 1 explained that it is necessary to incorporate TECOP (Technical, Economical, Commercial, Organizational, and Political) in the risk management system since all the types of risks influence each other. Dealing with each type of risk separately will only lead to schedule delays and higher costs. An intriguing answer that was given by expert 1 is that while he was reviewing the risk register, he found that the schedule risk impacts were hardly there. Lastly, the experts mentioned that they have started to implement an integrated system of all the risks since January 2021.

6.5 Discussion and Limitations

In this section the research findings are discussed. Second, the limitations of this study are described.

6.5.1 The impact of uncertainties on Morale

The first observation of the interviews is the difference between the answers of group A and group B. The results showed that group A experienced high uncertainty, while group B experienced very low uncertainty. This is due to the fact that group A is the old staff who had to work on the project since 2018 and experienced the scope change and its impacts. Group B is the new team who attended the project in 2020, after the scope change occurred. Therefore, Group B haven't experienced the high impacts of scope change. Group B did not experience high design uncertainty either; therefore, their motivation was not impacted instead they described their experience as interesting and challenging.

On the other hand, group A motivation was extremely impacted due to the high design uncertainty resulting from the scope change. Since the increase in uncertainty due to scope change led to more rework (Forcada, et al., 2017). This continuous rework made the team feel unaccomplished, demotivated, and exposed them to high stress (Dubrin, et al., 2001). The problem with rework is that it's a vicious cycle. The more the rework, the more the staff will lose interest in doing their task, hence affecting their morale negatively. As a result, this will yield a poor quality of output and eventually lead to more rework (Dye, 2011). Moreover, the team was skeptical about the project end goal since there was no progress. This is one of the effects of uncertainty as it increases staff cynicism and leads to lowering both the job satisfaction and the staff motivation (Dubrin, et al., 2001).

To overcome the loss of staff morale, the experts suggested some recommendations. First, sending everyone home till the impact of scope change was figured out was better for the team. This is because the team suffered from feeling helpless and not knowing or understanding the changes and how to cope with them during their presence on the project. As stated by one of the experts "It's difficult for the designers to say I don't know because the designer wants to have 100% certainty". According to Cooper et al. (2009) postponing the deadline would have been more effective in reducing costs. Although, there is a risk that part of the project team might not return (Bakker, 2020).

Moreover, another expert mentioned that the occurrence of scope change was not communicated between the design team in the beginning. This led to more questions and gossip within the teams and increased the uncertainties within the team. According to Ariely (2009) team members must be informed of project changes and the reason for the occurring changes. Not to mention that communication is a key factor that influences the staff morale (Gauvreau & Belout, 2004). Therefore, the lack of both good communication and clarification of the problem led to a decrease in the team motivation

Second, the results showed the importance of project leadership on Morale (Gauvreau & Belout, 2004), especially during times of uncertainty. The experts confirmed that there was a decrease in design uncertainty and a positive impact on their morale with the new design manager. The first reason explained by the experts is that the new design manager's focus is not only limited to the process but also communicating about the technical aspects. According to LiuYang, Liu, & Fellows (2010). Leadership should have both processes based and people-based management skills in order to impact the team performance. The second reason is that the new design manager was able to clarify the tasks required from the team. Team members seek guidance from the design manager on the future tasks. Therefore, it's important for the design manager to have good communication and give proper information and task objectives to the team (Leighton Group, 2010). This will build positive team dynamics and improve the team morale (McCalister, 2016)

6.5.2 The impact of risk management on Morale

Based on the results of the interviews with the two risk managers the analysis will be conducted. There are two main reasons that increased the impact of the project risks. The first one is underestimating the costs resulting from the scope change (Ford & Lyneis, 2019). Cost underestimation happened due to neglecting the overhead costs, since the time needed to manage the staff and the communication in the organization was not considered. in addition to underestimating the time needed to get the permits. Underestimating the required time for the tasks to be completed impacted the risks, led to schedule delays, and increase in costs.

The second main reason for increasing the impact of project risks is poor risk management. According to the results, planning risks and financial risks were managed and assessed separately till the end of 2020. By separating both types of risks, the impact of schedule delay that is shown in the planning risks will not be considered while calculating the financial risks. Accordingly, the financial risks will be underestimated. This explains why one of the experts mentioned that the schedule impact in the risk register was quite low.

Risks resulting from the scope change impacted the staff morale due to the continuous rework, high pressure, and stressful atmosphere. Eventually, this led to burn outs for some of the staff; in which some of them took leave and some others quit the project. Not to mention that working on a project in such a critical site location for two extra years than it was planned is also quite challenging. The continuous delay of the project can lead the staff to lose trust in the organization's potential, decrease in morale and tendency to leave the project (Ferede, 2020).

To overcome the loss of staff morale, the risk managers gave three main recommendations. The first is to stop the project and investigate the impacts of the scope changes before taking a decision based on limited information. The second recommendation is to have professional managers who can communicate with the team, have the tendency to listen to the problems and help the staff in solving them (Bhoola et al., 2014; Mantzouka, 2019). Finally, both risk managers insisted on the importance of having an effective risk management system; in which all the risks would be incorporated to avoid schedule delays and higher costs.

To conclude, scope change led to more rework, increased the uncertainty, and highlighted the impacts of poor risk management. Moreover, the high uncertainty and poor risk management led to more rework, which impacted the staff morale. Accordingly, uncertainty and poor risk management were incorporated in the main model. Figure 40 below shows that poor risk management and higher uncertainty influence the number of rework cycles of scope change leading to decrease in morale.

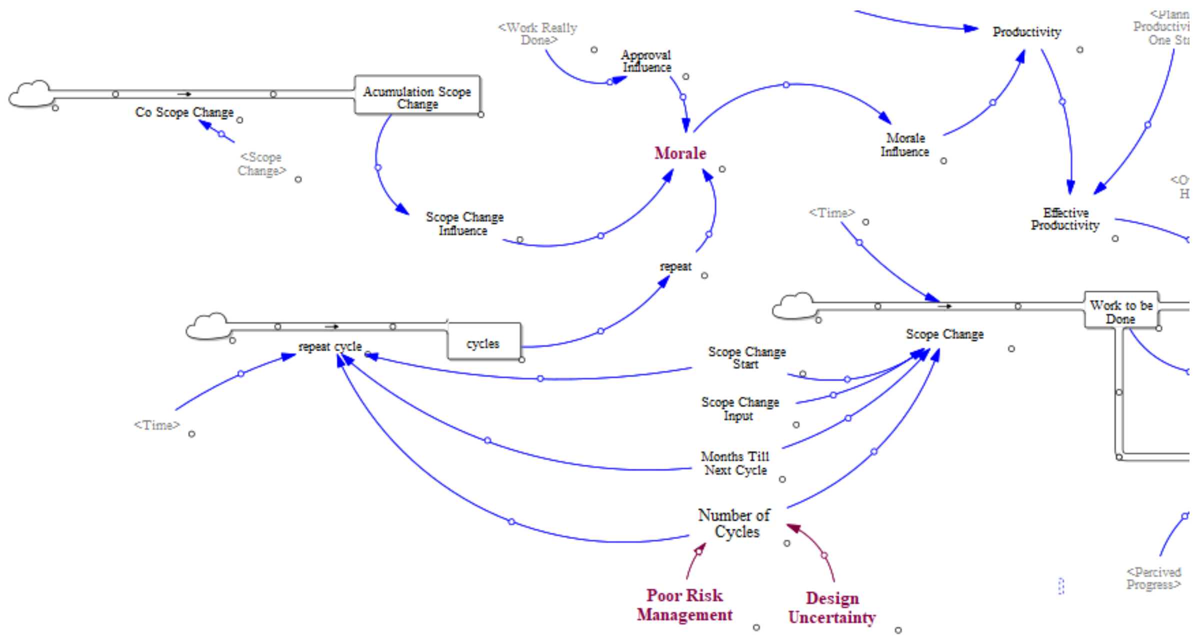


Figure 40. Poor risk management and Design Uncertainty in model

From this model it can be predicted that uncertainties and poor risk management will lead to decreased morale. In chapter 4 it was shown that decreased morale will lower the staff productivity and hinder the project progress. Accordingly, it can be concluded that uncertainties and poor risk management can eventually impact the project progress, leading to cost overruns and time delays (Thompson & Perry, 1992; Christodoulou, 2021).

6.5.3 Limitations

The first limitation to be considered is that a sample of seven interviews does not reflect the experience of the staff of the whole project. Second, the author found a limited number of experts who attended the project before and after the scope change. This is due to the fact that many people of the old staff have already left the project. Such an aspect resulted in having limited reflections of interviewees who experienced the impact of the scope change. Third, it’s important to consider that these results reflect the contractor’s side only. Hence, there could be biases from the contractor in focusing on blaming the other side (The Client). So, a reflection from the client's perspective would have given a better insight on the problem. Moreover, due to the time constraints the author could not quantify the impact of design uncertainties and poor risk management on morale. This is because obtaining these values will require further investigation and interviews with the case experts.

6.6 Conclusions & Recommendations

This section provides the final conclusions of the individual research and aims to answer the two sub research questions. Subsequently, recommendations are provided for further research.

6.6.1 Answers to the Research Questions

1- *How was morale impacted by design uncertainties and risk management?*

The first sub research question is divided into two parts: the impact of design uncertainties on the staff morale, and the impact of poor risk management on the staff morale. According to the results, scope change increased the uncertainties. The higher the uncertainties, the more rework that had to be done by the team during the scope change. As explained by one of the experts, the repetitive adjustments on the same design for almost two years caused frustration and tension in the team and negatively impacted the team morale (Dye, 2011). Moreover, the higher the occurrence of uncertainty, the higher the staff cynicism, which also leads to decrease in staff morale (Dubrin, et al., 2001). Furthermore, not communicating the occurrence and the impact of scope change increased the uncertainties within the teams and led to decrease in the staff morale.

For the second part, it was shown that due to poor risk management, risks were underestimated, which increased the cost of the scope change. Poor risk management caused more rework, which led to team frustration, high stress, and pressure. Not to mention that dealing with rework for a long period of time led to burn outs for some of the staff. Hence, rework resulted from both uncertainties and poor risk management, leading to decrease in morale.

2- *What could have been done to overcome the loss of morale?*

The results showed that there are three main actions that should have been done to overcome the loss of morale resulting from design uncertainties and poor risk management. First, all the experts agreed that it would have been more effective to stop the project and investigate the consequences of scope change before making the decision to continue. Second, the seven experts explained that having an experienced skilled manager is crucial to deal with the high risks and uncertainties. A good manager should be someone who is able to deliver proper information and task objectives to the team. Moreover, a skilled manager should ensure good communication with the team and is approachable to help the team in solving the issues faced during the scope change (Bhoola et al., 2014; Mantzouka, 2019). Project leadership has a significant influence on the staff Morale (Gauvreau & Belout, 2004). Finally, according to the risk managers, it's essential to consider the impact of different types of project risk on each other. To do so, an effective risk management system should be implemented. This should be applied to avoid underestimating the influence of a risk on the other, which can lead to schedule delays and higher costs.

6.6.2 Recommendations

General Recommendations

Throughout this research, several opportunities for future research have been identified. As mentioned in Section 6.5.1 the research has some limitations. The components were based upon the findings of the literature review and structured interviews but selected by the judgement of the researcher. Therefore, it is highly recommended to validate the results with a variety of experts with an experience on the impact of the scope change.

Case Recommendations

Based on the conducted research, there are three main recommendations that should be considered by LevveL to avoid design uncertainties and improve risk management. First, implementing a transparent and open environment within the teams of the organization is essential to avoid uncertainties, and distrust of the individuals towards the organization, especially in difficult times such as the occurrence scope change. Second, it's important to ensure that the hired managers have the ability to focus on both the process as well as the technical aspects in the project to fully support the team. The manager should have the skills and experience to lead and communicate effectively with the team during uncertain times. Finally, an effective risk management system should be implemented; in which all types of risks are incorporated during the risk assessment.

7 Influence of optimism bias on decision-making

In this chapter, one of the authors (Igor Peco) was researching a topic closely connected to the project individually. After introduction, the literature review is presented, following with the research question and methodology. Finally, results are presented, and the conclusion of the chapter is given. Additional documents can be found in the Appendix B.

7.1 Introduction

The topic that was researched is optimism bias. This topic was selected based on how often the topic was brought up, in the structured and semi structured interviews, that the author was involved in, during seven months of his work with the LevveL consortium on the Afsluitdijk reinforcing project. It was often debated whether the decisions made in different stages of the project were fully objective and feasible.

7.2 Literature review

To better understand optimism bias and subsequently choose the suitable methodology for researching it, first literature study had to be done. The literature was gathered using TU Delft repository, Research Gate, ScienceDirect and Google Scholar, and the following keywords were used for filtering the results: Optimism, Bias, Project planning, Project management, Forecast mistake, Expectation management.

The judgement of the project as a failure comes after the project completion and is usually defined as project not reaching aimed performance(profit, quality, aesthetics, etc.). This failure is often a consequence of the project not performing well or the project had unrealistically high expectations (Tyebjee, 1987). As the goal of this chapter is to research the effect of optimism bias on decision making, the latter one will be focused on.
Several researches showed that the planned duration, costs, and benefits of the project were highly inaccurate (Flyvbjerg, 2002; Arena, 2006; Dantata, 2006; Flyvbjerg and Stewart, 2012), with that pattern repeating itself over the last decades (Flyvbjerg, 2002). In the study that was

awarded with the Nobel prize, Kahneman and Tversky (1979) named this common behavior as "planning fallacy". They stated that this is because people involved in planning take the "inside view" focusing on the specifics of the plan, rather than looking at the outcomes of the similar actions already completed, which would be the "outside view". By using the 'outside view' the planners can bypass both optimism and advocacy biases. Kahneman and Tversky (1979) also argued that the effect of the "planning fallacy" will still be in place, even if planners are aware of it.

Case studies from Cyert, Dill and March (1958) showed that "expectations are by no means independent of hopes, wishes and the internal bargaining needs of sub-units in the organization both conscious and unconscious". Although, author's intentions in the beginning were to only investigate unconscious biases, a decision was made to research both types of biases, which will give holistic knowledge of the topic, enabling the author to construct better questions for the interview and analyze the results in a more professional way.

Advocacy bias or strategic misrepresentation is a type of conscious bias, referring to the process where a manager overestimates the benefits of the project, while underestimating the risks, with the goal of representing his project as more favorable, and increasing the chances to win the bid (Wachs, 1989; Flyvbjerg, 2002; Tyebjee, 1987).

Optimism bias is a type of unconscious bias, making the psychological explanations for inaccurate forecasts. According to Flyvbjerg, (2006), this is because planning is subjected to the cognitive predisposition of most people to judge future events in a more optimistic way than shown by actual experience. This was also confirmed experimentally, since Martin and Stang (1978) reviewed a number of experiments and concluded that people inherit the positive stimuli in the act of the planning itself. It is important to note that optimism bias is not intentional and represents the self-deception of the planner. The starting point of the optimism bias is the need for a decision to be made. Because of that, doubts must be put aside for the decision process to continue (Balderston, 1987). It is shown that the planner can gain the illusion of control over uncontrollable events (Langer,1975). A summary of cognitive predisposition related to the optimism bias is given in Figure 41, by Tyebjee, (1987).

Type of bias	Relationship to optimism bias
Availability	Organizations tend to publicize new product success stories more than failures. Hence, the frequency of success is overestimated.
Selective perception	Anticipation of what one expects to see biases what one does see; people seek information consistent with their hypotheses; people downplay or disregard conflicting evidence
Social pressures	Individuals will not voice opinions that threaten any consensus.
Overconfidence	The uncertainty in a prediction is considered to be lower than that warranted by the available facts.
Wishful thinking	People's preferences for outcomes of events affect their assessment of the events.
Illusion of control	Activity concerning an uncertain outcome results in feelings of control over the uncertain event.
Success/failure attributions	Tendency to attribute success to one's skill and failure to chance; past failures are discounted.

Figure 41. Biases influencing Optimism Bias (Tyebjee, 1987)

Having all this in mind, the individual research question was formulated as follows:

RQ: How did optimism bias influence decision making ?

In the next section, the author will present the methodology that will be used for answering the above-mentioned research question.

7.3 Methodology

To answer the proposed research question, the author decided to undertake a set of semi-structured interviews with experts from the LevveL consortium. While some researchers argue about the usefulness of this methodology for data gathering, and the extent to which that data can be relevant (Teski and Climo, 1995; Grele, 1998; Thomson, 2006), this methodology is still commonly used to gain in depth information (Reed, 2009) and information that can not be extracted from other sources (Armstrong 1997; Thompson 1998). Based on the literature study and the accumulated knowledge about the project, the author developed the set of questions for the interview. Two important events where decisions were made, were identified, namely: the beginning of the project and tendering phase, and the client induced change (WOG). The questions were created with the goal to guide participants through decisions that were made around these two points in time. The interview itself was divided into five sections and had a forecasted time of completion in 45 minutes. The questions for the interviews are presented in Table 5.

Table 5. Interview Questions

Personal
What is your profession? How many years of experience? What was the previous project you have been working on? Was it a success ? In what respect?
Project
What was/is your position on the project? How would you consider this project, regarding time, money, size, difficulty ?
Tender
How was the tender document developed? What were the techniques used in defining the tender documents? How many people were involved? Which disciplines were involved? Were there any unexpected events during the creation of tender? If yes, which? How was coped with such unexpected events? Was the resulting tender bid realistic and feasible? Why? What could have been improved in the tender - overall?
WOG - Client induced change
How was the WOG document developed? What were the techniques used in defining the tender documents? How many people were involved? Which disciplines were involved? Were there any unexpected events during the creation of tender? If yes, which? How was coped with such unexpected events? Was there a contingency budget and buffers to cope with unexpected events? Were these used? Was it enough? Was the WOG realistic and feasible? Why? What could have been improved in the WOG - overall?
Final
Why the project was not stopped, after identifying the errors? What would have been the consequences of stopping the project? What are the lessons learned from this project?

The personal part of the interview was about participants' education and profession, to give the author information about the experience that participant has. Here also a question about their previous project, before joining the project of reinforcing the Afsluitdijk, was asked, for gaining the information does the participant come from a successful project or from a failure, since this could affect their decision making.

The project part of the interview involved some general questions about the project and the position the participant has or had on the project. In this section participants were also asked to describe the project regarding size and difficulty, allowing the researcher to grasp the subjective feeling about the project, participants have.

The tender part of the interview contained questions about the tendering process. The aim with questions in this part was to give the researcher insights about how the tender was developed and where there were risks that fired during the process. At the end of this part, participants were asked about their opinion of how realistic the tender was made and what would they improve if they had a chance.

The WOG part of the interview contained questions about the client induced change (WOG). The aim with questions in this part was to give the researcher the insights about how the WOG was developed and where there were any risks that fired during the process. At the end of this part, participants were asked about their opinion of how realistic the WOG was made and what would they improve if they had a chance.

In the final part of the interview, participants were asked about stopping the project. In this part the questions were formulated to give the researcher participants subjective opinion of why the decision for the project to continue was made and what would be the effects of making an opposite decision.

Sampling for the interview was done with help from the thesis supervisors from the company, based on the requirements proposed by the author. Requirements for the participants were that they were closely involved in the planning or decision making in one, and preferably both of the two points in time.

7.4 Results

After identifying the appropriate candidates, all interviews were conducted within a time gap of a few days between them, to assure that none of the participants experienced something different from the others. The interview started with the author introducing himself and the purpose of the interview. Then participants were made aware of the structure and duration of the interview. The author decided for interviews to be anonymous, giving the participant the option to fully express his attitudes without having to fear of undesirable consequences of revealing them. After the interview all participants received a summary of the interview for approval.

7.4.1 Personal

The author interviewed 4 male participants. All participants were highly educated, and had different professions, mainly project managers, contract managers and project planners. Half of the participants have more than 10 years of experience, while the other half was working more than 20 years in their respective field. When asked about previous projects that they have worked on, 3 out of 4 participants stated that they come from a project that was a failure, both regarding time and money. These results are shown in table 6.

Table 6. Results of Personal section of the interview

	Gender		Experience (Years)		Previous project	
	Male	Female	>10	>20	Success	Failure
Participants	4	0	2	2	1	3

7.4.2 Project

The project part of the interviews revealed that half of participants are not working on the project anymore. All of the participants had an appropriate role in the project regarding their professional and educational background. Also, all of the participants had a mutual opinion that the project of reinforcing the Afsluitdijk, has a big and very complex scope. Some of the participants would use the term ‘program’ instead of project to represent the size of it, while the others referred to it as an ‘experiment’ to describe the complexity and uncertainties that are involved. These results are shown in Table 7.

Table 7. Results of Project section of interview

	Currently working on project		Project perception (scope, cost, time, difficulty)	
	Yes	No	High	Very High
Participants	2	2	1	3

7.4.3 Tender

Only one of the participants was involved in the tendering procedure, while the other three joined the project in a later stage (Table 8). The tendering bid was made using well established techniques of following the bid document provided by the client and narrowing down the possible solutions until the final one was made. A lot of people, from different disciplines and parties were involved in the development and reviewing of the tender bid. When the only participant that was involved in the tendering was asked if the bid was realistic, he stated that before the disruptions occurred, it indeed was realistic, and that all parties involved reviewed it and concluded the same. He also stated that the tender bid should be improved by shifting some of the major risks from contractor to client. One of the project managers that was not involved in the tendering procedure, expressed that the tender was not realistic, as it underestimated the time and the money for the project.

Table 8. Participant's involvement

	Participant 1	Participant 2	Participant 3	Participant 4
Tender			X	
WOG	X	X	X	X

7.4.4 WOG

The WOG part of the interviews reveals that all the participants were on the project when client induced change (WOG) happened. All of the participants expressed that the biggest problem in this phase was that WOG was not fully defined. Regardless of that, clients made pressure for the project to continue, and that decision was accepted by the LevveL consortium. All of the participants described this as an unusual decision, since WOG is usually first fully defined before implementation. Multiple disciplines from different sectors were involved in the creation of the WOG, using traditional methods of focusing on the project and its details, while gathering the relevant data about the impact of the scope change on each department. As the WOG was not fully defined, it went to several changes resulting with many interactions and revisions, with each new one bringing not only the change in the design but also changes in the client's requirements. All of the participants stated that they had numerous meetings with different parties involved, both inside and outside the Levvel consortium. Apart from leading to the huge amounts of time and energy spent on those, it also resulted in a chaotic atmosphere, without any opportunity to focus either on daily tasks or WOG. During this time, all of the participants agreed that the communication with the client was not ideal. When asked if the WOG was feasible, all of the participants said that the plans that were made would be feasible, if the design did not change constantly and if the client would have kept the good cooperation. Finally, 75% of participants, when asked what could have been done better, said that the project should have been stopped until the WOG is clearly defined.

7.4.5 Final

In the final part of the interviews, participants revealed that the decision to continue with the project was made from higher management, regardless of the advice from 3 out of 4 of them, to stop the project. According to those participants, the reasons for this decision came as a result of clients and higher management being unable to really understand the complexity of the scope change, and the strong political pressure that was present on the project from the beginning. Half of the participants stated that difficulties of stopping the DBFM contract was also the reason for not doing so. When asked about the consequences of a hypothetical stoppage of the project, all participants agreed that the positive consequence would be less cost overruns and delays, while the negative consequence would be more political pressure and loss of reputation for the LevveL. Finally, all the participants were asked what the lessons would be learned from this project. Their answers are presented in Table 9.

Table 9. Lessons learned from project

Lessons from the project	
Participant 1	
Stopping a project is an option	Don't implement the change, finish the project as planned, and then define needed modifications
Participant 2	
DBFM not the right type of contract for this big contract, especially because of risks	
Participant 3	
The effect of bad publicity on decision making should be lower	It is hard to explain complexity to the client
Participant 4	
Change and uncertainty should never take over the project	Always have a clear WOG before implementing it, don't do it in parallel

Summaries of the interview with each of the participants can be found in Appendix B.

7.5 Analysis

During the interviews, the first observation that can be made is that it was hard to find a participant who has been on the project from the beginning. With the project going through constant changes a lot of people left the project while new people were hired, resulting in few participants that could talk about both the tendering phase and WOG. Since this was the case, it was hard to conclude were people making the tender more optimistic, as they are not the one that will implement it.

7.5.1 Contract type

Most of the participants stated that the DBFM was not the right choice of the contract for this purpose. DBFM types of contracts are quite sophisticated and complex by their sole nature. With the contractor responsible for the financing of the project a lot of risks are allocated on the contractor side, including major risks that the contractor usually doesn't have any influence on. When deciding how to approach risks, namely should we have accepted, avoided, transferred, or reduced them, a major contributor to decision is in the attitude. Risk seeking attitude will have a more optimistic perception of risks, while risk averse attitude will have a more pessimistic influence on perception of risks (Nicolas, 2020). Since the DBFM is a riskier contract for the contractor, a conclusion has been made by the author that optimism was involved with the decision to tender the project as DBFM. What is not fully clear, was whether this was an example of optimism bias where an unintentional case of self-deception happened, or it was an act of advocacy bias with the goal to win the tender. Interesting to note here is that the project as Afsluitdijk, a part of the flood defense system of the Netherlands, where the highest priority has to be availability, due to its safety function, was tendered and accepted by the client as a DBFM contract. In the author's opinion a project of that size and importance should have the risks allocated to the party that has the biggest chance of handling them. In the end when risks do fire, especially this big and influential scope change the DBFM contract type showed extreme difficulties of overcoming them. This is mostly because the financing of the project goes to the contractor in the DBFM contracts. This requires contractors to make sophisticated calculations about the loans and expenses, in order to deliver the project but also make profit. When the scope change is introduced, it makes a disruption to these planes of the contractor. If the contractor is the one to finance the scope change, he will have to reduce his profit or even worse, lose money. The contractor, of course, wants to avoid this at all costs. On the other side, there is a client, who doesn't want to be involved financially in this project, because it was tendered as a DBFM, where one of the clear obligations of the contractor is to finance the project. If the parties are unable to agree, who is the owner of the scope change and to what extent, this situation usually results in a legal dispute between the two parties.

7.5.2 Tender and WOG development

Looking at the development of the tender and WOG, the traditional inside view approach was used for both of them. Large teams of people were focused on the project and its details, communicating between different departments until the estimate and the plan can be made. Another observation was made about how sure participants were that both tender and WOG were realistic, if the change did stop influencing the project in one moment. Author concludes that this result makes sense since, even a large number of people from different departments and parties were involved, everybody involved was using the same inside view and logically gained similar results. While the outside view was made for forecasting the time and price of the project in the planning stage, like tendering, similarly it can be used for forecasting the effects of a scope change. Instead of focusing on the project and how to assemble all the durations together, planners could have used the outside view and perform a simple statistical forecast based on how similar projects reacted to scope changes in the past. Also, it can be argued that LevveL was not aware of the optimism bias as a phenomenon since nothing seemed done to reduce it. Another possible phenomenon that might have occurred is group thinking. Group thinking occurs when a group of individuals reaches a consensus without critical reasoning or evaluation of the consequences or alternatives, mostly due to a common desire not to upset the balance of the group (Janis, 1971). This can also explain why all the parties from Levvel accepted both tender and WOG.

7.6 Conclusion

Stated in the literature, the root for optimism bias is always in the need for decision making. In the beginning that decision was to make a bid for the tender, while in the latter case it was the decision to incorporate the change to the project. After both decisions the next step is to plan how that goal will be achieved. As the planning process is influenced by the optimism bias, caused by the cognitive predispositions shown in Figure 41, the forecasts that are made are inaccurate. This is shown in Figure 42a.

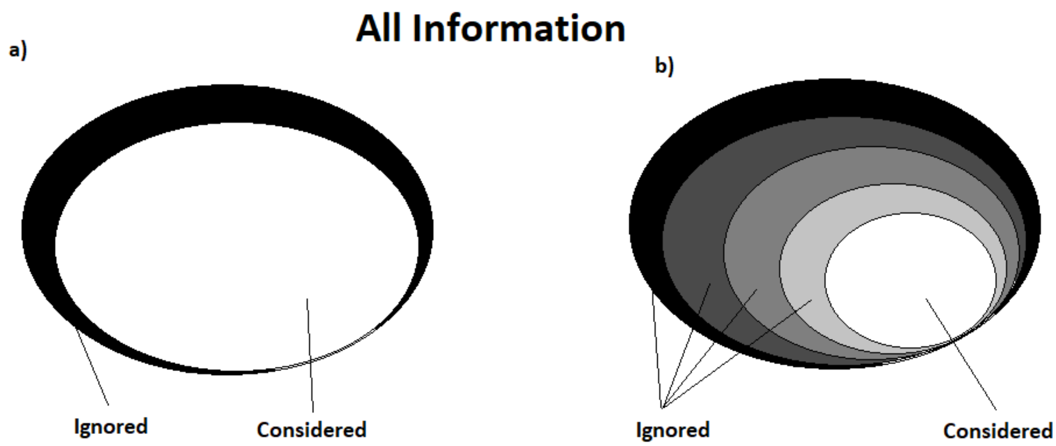


Figure 42. a) Planning Fallacy and b) Accumulation of Planning Fallacy

As that process of planning becomes repetitive because of the constant scope change, the author hypothesized that something that would be suitable called ‘accumulation of planning fallacy’ is happening. Namely, if the first plan that was made already had some optimism bias and ignored some information, because of the cognitive predispositions, then every next iteration and adjustment to the plan will be built on that inaccurate information and on top of that will have its own part of information that will be ignored, again caused by cognitive predispositions. Iteration through iteration, we will arrive at our final plan that almost reflects a theoretical chance for success. With so much information ignored, that plan represents a forecast that the project would be done in record time, with highest productivity and none of the risks firing, which is just one of the many more realistic options and is usually far from the truth. This is shown in Figure 42b. It should be also noted that the complexity and interconnection of various activities involved in this project, could have an amplifying effect on the negative influence 'Accumulation of Planning Fallacy' already had. For example, this can be that ignoring or underestimating some factor for a specific object, will not have an immediate negative effect on the progress of that specific object. Instead, when it comes to the interface with another object, or after a risk fires, the underestimation will be discovered, resulting in more rework and bigger consequences, than it would be expected or planned for.

Having this in mind, the author would argue that the optimism was present almost from the beginning of the project. The effect of the optimism bias was probably increasing during the project, having the biggest influence during the duration of scope change. Since every new scope change, meant new iteration of the planning process, resulted in probably more and more optimistic plans. On top of that, objectively, the project was falling behind schedule, so ignoring more and more information, as an effect of self-deception could also be true.

7.7 Limitations

In this section, two limitations of this individual research were presented. Firstly, the sampling of interview participants was limited, resulting in limited information gathered about the tendering procedure. Also, interviews maybe should be structured, in contrast from semi-structured. In situations like this, it was observed that participants tended to change direction of the interview, trying to justify their decisions and behaviour in the given time. Second limitation was concerning the hypothesis about 'Accumulation of Planning Fallacy'. This hypothesis was made by the author, purely based on knowledge gathered about optimism bias in this research. However, this hypothesis could be tested experimentally in suitable conditions. This was not incorporated in this research, because of the time limitations.

7.8 Recommendations

After finishing the research, several recommendations for further investigation of this topic were formulated. Also, recommendations for LevveL and recommendations for incorporating the knowledge gained in this research to the model development were given.

7.8.1 Recommendation for further research

Firstly, it is recommended to investigate approaches for implementing outside view in planning discipline. While in literature the notion of outside view can be found, the author had difficulties to find any standardized framework of how the outside view should be used. This framework should consist of guidelines on how to find, filter, adjust and use the data of similar projects.

Secondly, the author suggests that the hypothesis of accumulation of planning fallacy could be tested. As the planning fallacy was proven experimentally, accumulation of planning fallacy could be verified the same way. The experiment itself would have to be more complex, involving different teams working on multiple iterations of the planning process.

7.8.2 Recommendations for LevveL

For LevveL consortium, the author recommends that the awareness of planners and managers about the planning fallacy should be investigated. Regardless of the fact that awareness of the optimism bias does not reduce it, it makes an important starting point for coping with it. Companies have more interest in introducing new techniques, if they are fully aware of the problems it will solve. Proposed methodology for this research would be using semi structured interviews to gather qualitative data about the understanding of the planning fallacy inside a company. Also, after the completion of the project, it is suggested to the consortium to spend time and resources to gather, check and document all the plans made for this project. Then an observation can be made about the percentages of plans that were delivered, and more insights about how influential optimism bias was could be gathered.

7.8.3 Recommendation for model development

After completing the individual research, the author came up with a way to incorporate the discovered information to the mutual part of the research. A variable Optimism Bias was made and placed inside the scope change part of the model, as shown in Figure 43. Since the optimism bias was affecting the project whenever a new plan for the scope change was made, Optimism

Bias was modelled as a consequence of Number of Cycles. On the other hand, as optimism bias was influencing the inaccurate forecasts, Optimism bias was modelled as an influence on Scope Change Input. This represented that the number of Work Packages that were introduced during scope change, was not accurately estimated, and in fact is bigger than forecasted. With the new variable qualitatively described, with its causes and consequences, to fully implement it to the model, quantification of the influences was needed. Since that was out of the scope of this individual research, the author recommends to future researchers, to model two influences, one explaining how number of iterations affect the planning fallacy, and second one explaining how planning fallacy affects wrong forecasts.

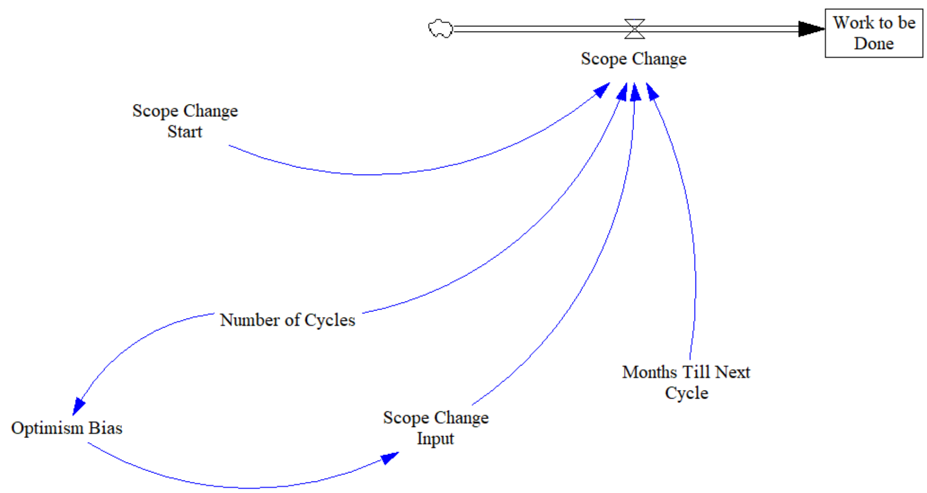


Figure 43. Optimism Bias in model

8 Discussion

This Chapter aims to interpret and discuss the findings and their implications. First, the research findings are discussed. Second, the limitations of this study are described.

With this research, the impact of scope change on the second order effects was studied using system dynamic modelling. Through SDM, the authors were able to visually model the second order effects of the LevveL case and define the linear and nonlinear relations between the identified variables. The qualitative model results showed that staff productivity was impacted by the managerial techniques such as hiring new staff, overtime, and schedule pressure (Chapman, 1998; Chang, 2017). These techniques were applied after the occurrence of the scope change in order to avoid delays. However, these managerial techniques also led to office congestion, increase in errors, and decrease in morale, and consequently lower productivity (Ford & Lyneis, 2019; Bakker 2020). The lower the staff productivity, the less work will be done, which will eventually impact the project progress and cause delays.

The quantified model showed that the second order effects highly impacted the project perceived progress leading to higher costs (Cooper & Lee, 2009; Ford & Lyneis, 2019; Bakker, 2020). It was shown that morale and productivity were the factors with the highest impact on the project progress (Leonard, 1988; Dye, 2011; Saldanha, 2018). Morale was observed to increase when a Work Package is completed and dropped when more rework was introduced due to the scope change (Dye, 2011). Since, the accomplished work became obsolete or rework, due to the scope change; morale highly influenced the project progress. Errors and schedule pressure were the least impacting factors according to the LevveL experts, which differs from the conducted literature review. According to the experts, schedule pressure was always present before and after the scope change. Therefore, scope change did not cause a huge impact on schedule pressure. Regarding the errors, the interviews conducted to investigate the impact of the design errors were held with the design managers. These managers only review the final work after most of the errors are corrected by the team. If the interviews were held with the team, the results could have been different.

When comparing the planned progress with the perceived progress it was shown that the second order effects of scope changes led to a 100% increase in the project duration compared to the planned one. The perceived progress was identical to the planned progress till the occurrence of the scope change. According to the experts, scope change led to more rework almost every 4 months. This is the time required for reviewing the design documents by LevveL and then by the client. Since the scope change was still happening, by the time the documents were reaching the client new changes were discovered. Accordingly, some of the submitted work became obsolete or reworked. It was observed that perceived progress dropped by 8% after every new cycle of scope change. Therefore, the model showed that the Perceived Progress reached 100%, resembling the completion of the project, after 40 months. Compared to the Planned Progress, this represents a 19-month delay, extending the duration of the project to almost double. To calculate the impact of the second order effects alone, the First Order Progress was compared with Planned Progress. The results showed that the influence of first order effects of scope change to the project duration, resulted in 9 months of delay. Accordingly, it can be concluded that the impact of second order effects alone led to 10 months of delay (50% of delay) . If the impact of the second order effects of the design phase of the New Sluices resulted in 50% delay, it can be predicted that the impact of the second order effects on the whole project would largely influence the project progress and lead to cost overruns (Cooper & Lee, 2009; Ford & Lyneis, 2019; Bakker, 2020).

The model behaviour and structure showed satisfying results after conducting nine out of the twelve tests that are recommended in Sterman's book (2000). Accordingly, the author's concluded that the model is ready for use.

Further investigation showed that scope change increased the design uncertainties and highlighted the problems of the project risk management system. Both factors led to more rework which negatively influenced the staff morale. Therefore, adding design uncertainties and poor risk management in a dynamic model is expected to impact the staff morale. This can lead to further decrease in the perceived progress and influence the current results of the model. It was also observed that optimism bias in the project regarding decision making will increase the rework, which will reflect on the project progress.

The current research studied the impact of scope change on the project through the use of system dynamic modelling and addressed some of the organizational problems that impacted the project during the scope change. Accordingly, in this way the company is provided with an estimation of the time impact of second order effects resulting from scope change on the project. Moreover, the model highlighted the most influential factors that should be tackled for future projects. Furthermore, the company is offered areas that require attention and improvement regarding the project design uncertainties, risk management process and optimism bias currently in practice.

8.1 Limitations

In this section several limitations of the study are presented. First, limitations that were met in the phases of development of the model are shown, while at the end of the section, limitations about the research as a whole are mentioned.

8.1.1 **Model Conceptualization Limitations**

During the phase of model conceptualization, two variables that represent second order effects were excluded from the model. One of the second order effects that was not included in the research was the effect of working out of sequence. Authors decided to exclude this influence from the research because the project was still ongoing, and it was assumed that this data would be extremely difficult to gather. Second limitation of the research was that it did not show the influence of project management fully. While the research involved traditional strategies that management uses, it did not include a variable that would show the loss of focus caused by the repetitive change that was observed in the behaviour of managers.

8.1.2 **Model Formulation Limitations**

During the formulation phase of the model development, authors also found a few limitations. Namely, the values that were created from assumptions of the interview are relatively vague. This is a consequence of the limited number of interviews that were conducted. The consistency of the interviews also had an effect on this, as people from different positions or levels of hierarchy in LevveL were interviewed using the same questions about the same topics, which resulted in inconsistent results.

Another limitation of the model is that it is not showing the exact Work Packages that were re-done multiple times, but rather it just takes the percentage of Work Packages from the corresponding stock variable. It was stated by the SD experts that this could be done in different SD software, but that Vensim software does not support these mechanics.

Lastly, the model did not consider that the staff from the project could also be dismissed, and not only hired. Therefore, this is a limitation that should be considered in future research.

8.1.3 Model Testing Limitations

During the testing phase of model development, authors came across several limitations. These limitations were due to the fact that some of the tests required a comparison with similar cases; and these data were not available from LevveL. Another reason is the time constraints. These limitations were part of the reasoning why out of twelve tests, one was not completed, and three were not done.

8.1.4 LevveL Expectation Limitations

During the final stages of the research, experts from LevveL argued that the model should have two independent productivities for the regular part of the scope and for the changed part. This addition would represent reality more accurately, but this idea was not implemented due to the time constraints of the project.

8.1.5 General Research Limitations

Finally, the biggest limitation of the model is that it represents the view of only one out of two parties involved. Since the model was developed with views and values that were gathered through the interviews with experts from LevveL, one can argue that the model is biased. Clients' opinion about scope change, and the influences it will have on the project were not considered in this report, as it was outside the scope of this research.

9 Conclusion and Recommendations

This Chapter provides the final conclusions of the main research and aims to answer the main research question as well as the sub research questions stated in Chapter 2. Subsequently, recommendations for practice and future research will be provided.

9.1 Conclusion

This study researched the second order effects resulting from the scope change. The research consisted of two parts. First, to identify the variables impacted by the scope change, exploratory research methods were used. As a result of the research activities, new insights and perspectives on the situation are developed. Second, the model was developed using the Vensim software. Following from the objective, the main research question formulated was "How could second order effects of the project scope change be quantified through system dynamics modelling?". To answer this research question, four sub-questions were formulated. Sub research questions two, three and four as well as the individual questions will be answered separately through the use of Sterman's phases of model development approach (2000).

Sub question 1: *"What are the consequences of scope change?"*

An extensive literature study was conducted to find the consequences of scope change. Moreover, respective interviews were held with project experts to confirm the compatibility of the literature review results with the project case. It was found that scope change impacts several factors; rework, productivity, morale, errors, schedule pressure, overtime, hiring new staff and office congestion (Cooper & Lee, 2009; Bakker, 2020). These factors are the consequences of the scope change and are known as the second order effects.

Sub question 2: *"How should the model qualitatively be described to show delays caused by the scope change?"*

The factors identified in the results of sub question one were inserted in the model. Sterman's phase one and phase two; "problem articulation" and "dynamic hypothesis" were followed to develop the conceptual model. Accordingly, the causal loop diagram was created. To ensure that the causal loop diagrams were reflecting the real case problem continuous meetings as well as interviews were held with the case experts to confirm the loops. Hence, nine casual loops were defined: two of them are balancing loops and the other seven are reinforcing loops. Finally, the dynamic hypothesis was constructed by combining all the identified loops. The results of the dynamic hypothesis showed that Work to be Done influences morale and perceived progress but is influenced by scope change and errors. Errors are directly influenced by schedule pressure, overtime, and office congestions. Productivity is directly influenced by morale, schedule pressure, overtime, and office congestion. Hiring staff is indirectly influencing productivity through office congestion. Through displaying these relations, it was concluded that there is a linear and nonlinear relationship between scope change and all the defined factors. These relations showed that the occurrence of scope change led to an increase in the Work to Be Done, which impacted the identified variables and decreased the perceived progress. Accordingly, these observations were incorporated in the quantitative model

Sub question 3: *"How should the model quantitatively be described to show delays caused by the scope change?"*

The dynamic hypothesis formed in sub question two was used in building up the quantitative model. Sterman's third phase (2000), Formulating the simulation model to develop the quantitative model. The results of the planned model showed that a change in the Planned Staff or Planned Productivity by One Staff will impact the speed at which the project will be completed. Second, the actual model was developed. The results showed that scope change impacted the second order effects identified in the model, which hindered the project progress and led to the project delay. The results showed that scope change increased the initial project scope and was the main cause of hiring extra staff. It was shown that scope change impacted the staff morale leading to a decrease in productivity. To conclude the impact of scope change on the project, a comparison between the planned and perceived progress is conducted. The planned progress was 21 months based on the project tender. However, when the scope change was added, the first order showed a progress of 30 months. Thirdly, when all the variables were included, the perceived progress showed that the total influence of the scope change resulted in a duration of 40 months. Based on the result it can be concluded that the first order effect resulted in 9 months of delay when compared to the planned one. These results concluded that the project was highly impacted by the occurrence of scope change which led to 19 months of delay when compared to the planned duration.

Sub question 4: *"How does the model perform in showing the impact of scope change?"*

Sterman's fourth model development phase; model testing was used to answer the last sub research question of the main research. To determine if the quantitative model is fit for purpose and was correctly designed based on the initial conceptual model or not. After conducting several tests, it was concluded that all the tests successfully assessed the behaviour, structure, and the variables of the quantitative model directly, without examining the relationship between structure and behaviour. Based on the test results of the model, the authors agreed that the model behaved is ready for use.

It can be concluded by answering the four sub research questions, the authors' main research question *"How could second order effects of the project scope change be quantified through system dynamics modelling?"* is answered. First, a dynamic hypothesis should be created and confirmed through literature and continuous interviews till the hypothesis reflects the project case. Second, formulas should be created for the defined variables and values should be inserted in the model based on the case data. Third, the model should be simulated, and the perceived progress should be compared with planned progress. Then, the first order progress should be compared with the planned progress to quantify the first order of effects of scope change. Finally, to quantify the influence of the second order effect of scope change, the first order effects should be deducted from the total influence of scope change.

Finally, both authors formed their individual research questions during the journey of answering the main research question. The sub research questions of the first author "*How was morale impacted by uncertainties and risks?"* and *"What could have been done to overcome the loss of* *morale?"* concluded that uncertainties and risks can impact the staff morale through rework, lack of transparency, poor risk management and leadership. To overcome the loss of morale the presence of a skilled manager and implementing an effective risk management system, where all the different types of project risks are incorporated is essential. Moreover, it would have been wise to stop the project and investigate the impacts of the scope change before the decision to continue was taken.

The second author's individual question ”*How optimism bias did influence decision making?”* concluded that optimism bias influenced the decision-making process in the project. It was hypothesized that this resulted from the 'Accumulation of Planning Fallacy' that was happening during the iterations of the planning process. The proposed solution for overcoming optimism bias was the usage of the 'outside view', when forecasting the costs, durations, and benefits of the projects. 'Outside view' would bypass optimism bias and produce more accurate predictions.

9.2 Recommendation

In this final section of the report, recommendations for further research will be presented. The recommendations will be based on the findings and limitations of this research.

9.2.1 **Recommendation for future research**

9.2.1.1 Model Conceptualization Recommendation

To improve the second phase of model development, future researchers should investigate and include a few more variables to the model. Two most important variables that authors suggest for future investigation are working out of sequence and the loss of focus by the managers. First, a literature research should be done to fully understand these two behaviors. Next, they should be included in the qualitative model, where both causes, and consequences of both variables are presented. Finally, the exact values of the variables should be included in the quantitative model. These values can be gathered with any methodology that future researchers find suitable.

9.2.1.2 Model Formulation Recommendation

To improve this phase of model development, two recommendations were given. Firstly, to increase the accuracy of assumptions gathered from interviews with experts, future researchers should interview more experts. Those interviews should also have stricter sampling strategy, so the participants are fully aware of all the influences and consequences of the variable that is being quantified. For example, in this research errors due to rework are assumed to have small influence on the progress of the project. This is in contrast with findings from literature done in Chapter 3. The reasoning behind this was found in the sampling of the interviews. Participants that were interviewed about design errors were from higher management and probably did not have the accurate information about the magnitude of design errors provoked by rework.

Second, it is recommended to gather the necessary data for modeling the dismissal of the staff. With correct data this should be implemented to both New Staff and Old Staff variables. An outflow rate should be created from these variables, representing people who left the project during their training, and people who left the project after becoming productive, respectively.

9.2.1.3 Model Testing Recommendations

To improve the testing phase of model development, two recommendations are given. Firstly, more variables should be tested in the extreme condition and sensitivity tests. This will provide a more robust and accurate model. Secondly, future researchers should gather the necessary data from LevveL in order to compare the results from the model with real world data. This data was not available during this research, as LevveL did not decrease the progress of the activities that were impacted by the scope change.

9.2.1.4 General Recommendation

Since the research was done to reflect the contractor's view on the situation, and as that represents only half of the views, recommendation is given that similar research should be done to represent the client's perception of the matter. This research should present the client's understanding of causes and consequences of second order effects provoked by scope change.

Clients' perspective can be either modelled within the already available model developed in this research, or a new model can be created while using this research as a guideline.

9.2.2 Recommendation for practical use

As this research was done by two master students during their internship at one of the companies that is part of the Levvel consortium, two different strategies for the use of the model and the results it provided were created.

First strategy for LevveL would be to use the quantitative model developed in this research. For every object that was affected by the scope change, LevveL should use the model, and find the magnitude of second order effects. This could be done by updating the inputs of the model based on the object they are seeking to quantify. Since the unit of the effects in the model is time, conversion from time to money would have to be done. Impact of the second order effects for every object on the project should be observed in regard to the first order effects. For example, the model for the New Sluices showed that second order effects have the same impact as first order effects, but that might differ in another object in the project. Finally, this process should be repeated for every affected object of the project until the final amount is calculated.

The second strategy for LevveL would be to use the qualitative model developed in this research when discussing the costs with the client. While the quantitative model has some assumptions, the qualitative model is fully made based on knowledge from literature. This can be used when approaching a client, to increase the client's knowledge regarding the second order effects, while explaining the factors that occurred and the impact that they had on the project. Increasing the awareness of the client about the second order effects and their impact, could lead the client to recognize the extra costs provoked by them. Achieving this could result in resolving the matter in a more pleasant way, avoiding any disputes.

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Appendix

Appendix A - Main Research Interviews

Two interviews were done with two design managers at level in order to verify the model variables qualitatively and quantitatively. Expert 1 worked on the project before and after the scope change, then he left the project, Expert 2 only worked on the project after the scope change and is still the current design manager of the New Sluices. It's important to mention that some questions were answered differently by both experts regarding the % of rework and obsolescence due to the scope change. This could be due to the fact that expert 1 was present before and after the scope change so he was able to see more rework and obsolescence of the scope change compared to expert 2 who was present only after the scope change.

Secondly, both experts agreed that the % of errors were 10%, which is quite a low impact when compared with what the authors found in literature (Dosumu, 2013; Kikwasi, 2012). This justification for this is that due to their position as design manager, they receive and check the work after the staff has already reviewed the work and fixed the errors. Therefore, from their perspective the errors they notice are of low percentage. Moreover, the designers explained that the impact of the skills and experience of the new staff is not specifically errors but more of inapplicable solutions suggested by the new staff. From their perspective it is considered more of a waste of time than errors.

An interesting aspect that was mentioned by Expert 1 is that the main struggle the team faced due to the scope change is Uncertainty. Since a lot of people struggled with doing their job when there were a lot of uncertainties, this also led to inefficiency.

Expert 2 highlighted seven second order that in his opinion extremely affected the project:

1- Loss of reference since the design team had to do almost two years of investigations during the tender phase and all of this will be useless when the design scope changes. Then, the team will have to repeat the process of investigating the new structure.

Note: Loss of reference hints to all the design documents that helped the design team in developing their design.it also refers to the expertise who worked on the old designs and left the project after the scope change with all their extensive knowledge.

2- Loss of control of the interfaces, since in the tender they have identified all the interfaces of the whole project designs. But since several interfaces changed due to the scope change it will influence the New Sluices structure design. The design manager of the New Sluices can control every aspect of his own structure, but not of the other interfaces such as the architectural interface.

3- The project risk profile increases due to the increase of uncertainty. When the original design was submitted by LevveL to the client before the scope change the team was certain about the risks. However, after the scope change, they are not certain about the risks anymore. They will have to analyze it again and see if they missed any risks. So, after two years of risk assessment in the tender, all that is lost due to the scope change.

4- The changes that were imposed by LevveL and not by the client. For example, if there is a change by LevveL in the construction sequence, and there are also changes of the hydraulic requirements from the client; then all these changes will start influencing each other. So, the more changes you have in the project the more you will drift away from your control, and it's not a linear relationship, but an exponential one. So, if there were no changes of the hydraulic requirements from the clients, the effects would not have been that huge.

5- Loss of motivation because when it's harder to accomplish the task the staff will start to lose motivation. The loss of motivation also causes inefficiency which eventually leads the staff to leave the job. When these people leave, you lose all the experience and information that these people had.

6- Nature of the large infrastructure project, since you have to persevere in such a complex project. Since, there are many requirements, and you need to realize that there are many relations, which makes it different to proceed.

7- Increase of skepticism, when people become more skeptical about the team performance, the performance of the work done is affected. This is because the staff become less confident of what they do, which leads to lack of control.

Some of these second order effects were included in the developed model, such as loss of motivation. Some others were investigated in depth in the individual research such as the project risks.

Interviews Questions & Answers

Table 10. Q & A of the interviews with the previous & Current design managers of the new sluices

No.	Questions	Answer by Expert 1	Answer by Expert 2
1	Could you give a short introduction of yourself?	Structural Engineer who worked with LevveL the last couple years and the previous Design manager of the new sluices	the current Design manager of the new sluices
2	How did scope change affect the design team performance? Can you give examples?	The whole team was replaced by hydraulic specialists because the problem was more complicated than expected.	Loss of motivation, loss of control of the interfaces, and loss of references, and increase of skepticism
3	From your experience on the project, what do you think the % of scope change for the new sluices?	60%	20%

4	What was the % of rework due to the scope change?	100%	35%
5	What do you think is the % of Obsolete work for the new sluices?	100 %	15%
6	What was the % of rework due to the design errors?	10 %	5%
7	How long for an error to be discovered and how long for it to be fixed?	It varies	It varies
8	How did scope change impact schedule pressure?	Time pressure is always present, and it increased due to scope change	Delay of 6 month from the Engineering side
9	How did scope change affect the team morale?	It depends on each individual	Highly, since loss of morale led to inefficiency and people leaving the job
10	If you would give a % of the impact of scope change on morale what would it be?	A range between 10% to 50% decrease	20 to 30% depending on the individual
11	How did hiring or bringing new staff to the team affect the team productivity?	The new team productivity is zero in the beginning when they join the team and by time, they get up to speed	The new team productivity is zero in the beginning when they join the team then after the training, they are productive
12	How many designers were working on the design of the new sluices in the beginning, in between, and in the end/ just before you left?	6 people and they increased by time	20 people in the beginning and now 17 because 3 left the project
13	When did the new staff become as productive as the old team? After how many months?	After 4 to 6 weeks to	After three months of training
14	How many of the old design team were training the new staff of the design team?	All of them, and they lose ½ a day per week in terms of productivity (10%)	All of them, training 3 new people decrease the

			productivity of old team by 5%
15	How do the skills and experience of the new staff affect the work?	It causes waste of time	15% of extra time needed by the new staff to get the same results of the old team
16	What is the % of errors due to the skills and experience of the new staff, can you give an educated guess?	10%	Not errors more of extra time
17	Did you or any of your team experience office congestion during the time you spent on the design after the scope change?	Yes, before the lockdown	Yes of course, but I prefer office congestion than the lockdown
18	How did the office congestion affect you and your team?	After the scope change the office was so much more congested and that wasn't efficient and more irritating	The bigger the teams, the more challenging it gets to coordinate, and have good communication with the teams
19	What is the % of decrease in productivity due to office congestion?	Lower but can't give a percentage for that	5%-10%
20	Did schedule pressure lead to working overtime for the design of the new sluices?	10%	5%
21	What is the % of overtime you and your team had to work due to the scope change?	10%	5%
22	How did Overtime affect the Errors? Can you give a % of this error?	10%	
23	How did Overtime affect team morale? Can you give a % of this impact on morale?	It varies depending on the individual	It varies depending on the individual
24	How did schedule pressure affect the errors? What is % of error that was caused due to the schedule pressure	10% but cannot differentiate if it's because of the overtime or the schedule pressure	

25	How do finished parts of the design work affect the team morale? What is the % increase in morale? Can you give an educated guess?	Cannot give %, but it increases the morale	It increases
26	How did your motivation evolve overtime?	High in the beginning, low when the problem seems more complex than expected	I haven't seen the situation before I joined the project after the scope change
27	How did productivity evolve over time?	It's affected by morale, so as the morale decreases productivity decreases and it could also be vice versa.	I haven't seen the situation before, I joined the project after the scope change
28	What do you think are the main ones that decreased the Productivity?	Uncertainty, a lot of people struggle with doing their job when there is a lot of uncertainty, and I think this is the high impact of scope change	Low Morale cause 20% to 30% more time spent on the task
29	Do you have progress reports for the period you worked on the project that you can share with us?	Nothing I can share will really help you.	Some design drawings of the sluices
30	Do you have any suggestion/ recommendation of another designer who also worked on the new sluices that we can have a meeting with?	Yes, Hans Ramler, he managed phase 2 of the new sluices with the client	
31	What else should I have asked?	I am interested to see what your model will look like.	I am interested to see the model

Appendix B – Optimism Bias Interviews (by Igor Peco)

EXPERT 1

1. Personal:

What is your profession? How many years of experience?

Before Levvel, what was the previous project, you have been working on ?

Was it a success ? In what respect?

The examinee is project manager and project director for Bam Infra, has studied Civil engineering at TU Delft, with the experience of working with contractors for more than 25 years, 20 of those in DBFM contracts. The previous project was a sea lock as intern project director, and the project had cost overruns and schedule delays.

2. Project:

What was/is your position on the project ?

How would you consider this project, regarding time, money, size, difficulty ?

The examinee is not currently working on a project. He had a role in determining the cost and time impact of the change in the hydraulic boundary conditions to the scope. The classification of the project by him is extreme regarding time, costs, difficulty, and scope, referring to it as something that was never done before and semes more like an experiment. Suggest that also the type of the contract (DBFM) was not the best choice.

3. Tender:

The examinee was not working on the project in the time tender was made.

4. WOG - Client induced change:

> *How was the WOG document developed?*
>
> *What were the techniques used in defining the tender documents?*
>
> *How many people were involved? Which disciplines were involved?*

The examinee, and his team of six people from different disciplines, had a lot of back-and-forth meetings about the change with the client and existing planning team. There were discussing the impacts with each department. Each department would give their estimate of the impacts the change will have. Also, project management of Levvel was included in this process.

The planning was done by gathering the information from the project team. In that moment there were two plans, the tendered one and the one from summer 2019. Also changes in the design part were identified and their impact in the execution phase, for every department. One of the things that needed to be considered here were contractual requirements, for example the closing of the sluices.

A new high-level schedule was created, that went for a review from management team of Levvel. That was an ongoing process, especially because of the continuous changes, and the impact that they had.

Were there any unexpected events during the creation of tender? If yes, which?

Regular changes that were occurring, not only in the design, but also in clients wishes.

How was coped with such unexpected events?

Going through the process off discussions and gathering data from all the departments, all over again. Resulting in the schedule having a lot of revisions.

Was there a contingency budget and buffers to cope with unexpected events? Were these used? Was it enough?

There was none.

Was the WOG realistic and feasible ? Why ?

Yes, the plan was realistic, the failure resulted from the constant changes both in design and client requirements.

What could have been improved in the WOG - overall?

The project should have been stopped, giving the opportunity to resolve the situation in a more controlled environment, but also making it easier to distinguish which errors have been made clients and contractor’s side. A lot of risks fired and that could be stopped.

5. Final:

Why the project was not stopped, after identifying the errors?

There was political pressure on the project from the begging, but that is not the only reason for not stopping the project. In every phase of the project, project managers thought that it will be possible to cope with changes, especially with good cooperation with the client, that stopped when client changed the working team. While making those decision that the project is still feasible, optimism bias was present. Nevertheless, it is hard to decide to stop an ongoing project, especially whit the high-profile clients, and even harder if that high-profile client recently had a few projects with delays and cost overruns.

What would have been the consequences of stopping the project ?

The project would be much easier to control, resulting in less delays and cost overruns, but would increase the political pressure and reputation loss.

What are the lessons learned from this project ?

DBFM contract is not the type of contract for this type of project, especially because the risk for the contractor is too high for such a complex project. The project should have been continued as tendered and then finding additional solution for the discovered error or stop the project and work on the solution with the client in a controlled environment.

EXPERT 2

1. Personal:

What is your profession? How many years of experience?

Before Levvel, what was the previous project, you have been working on ?

Was it a success ? In what respect?

The examinee is project manager with Van Oord, working for more than 25 years in the field. The previous project he was working on is a port, and the project was a success regarding money and had no schedule delays.

2. Project:

What was/is your position on the project ?

How would you consider this project, regarding time, money, size, difficulty ?

The examinee is currently working on a project. He has a role as a project manager of the existing sluices, responsible for renovation and upgrade of them. The classification of the project by him is high profile project in the Netherlands that everyone is looking at. Because of that project was under enormous political pressure from the beginning. Also suggests that interdependency between objects on the Afsluitdijk is high.

3. Tender:

The examinee was not working on the project in the time tender was made.

Was the tender realistic and feasible ? Why ?

Tender was not realistic, because the project was underestimated, mainly regarding time and costs.

4. WOG - Client induced change:

How was the WOG document developed?

What were the techniques used in defining the tender documents?

How many people were involved? Which disciplines were involved?

More than 20 people were involved in creation of the WOG, from different disciplines. WOG team went into a cooperation mode with the client to try to resolve the issues. Also, different experts from the different fields, give their judgment on how long the incorporation of the change will take.

Were there any unexpected events during the creation of tender? If yes, which?

Regular changes that made the project from barely doable to nearly not doable.

How was coped with such unexpected events?

There was a tiny learning experience of how to cope with the next change that will come.

Was there a contingency budget and buffers to cope with unexpected events? Were these used? Was it enough?

There was none.

Was the WOG realistic and feasible ? Why ?

It is nearly doable, but the risk assessment was much higher than in the beginning.

What could have been improved in the WOG - overall?

Biggest effect to the situations has that client and project board, do not really realize the complexity of the matter. The cooperation with the client should have been improved, but the client kept the approach they had from the tender.

5. Final:

Why the project was not stopped, after identifying the errors?

That decision came from the higher management, regardless of the advice of the examinee to stop it.

What would have been the consequences of stopping the project ?

If the project was stopped a year ago, the losses in time and cost would be way lower than now. It would indeed lead to more political pressure and loss of reputation.

What are the lessons learned from this project ?

DBFM contract is not the type of contract for this type of project, especially because the risk for the contractor is too high for such a complex project.

EXPERT 3

1. Personal:

What is your profession? How many years of experience?

Before Levvel, what was the previous project, you have been working on ?

Was it a success ? In what respect?

The examinee is head of contract manager department, working for more than 15 years in the field. The previous project he was working on was not a success, with the project having several problems.

2. Project:

What was/is your position on the project ?

How would you consider this project, regarding time, money, size, difficulty ?

The examinee is currently working on a project. He has a role as a head of contract management. The classification of the project by him is very high in all of the categories.

3. Tender:

How was the tender document developed?

How many people were involved? Which disciplines were involved?

What were the techniques used in defining the tender documents?

The tender was developed following the guidance of the clients document for making the bid. Also, extended reviews of all the documents were done, and a lot of communication with the client was present at that time. A lot of circles of abovementioned processes were made, while in each one different part of the bid was tested. First a lot of options were included, but as the time was passing those options would be narrowed down, until the final solution is found. Also, the bid was reviewed from bank’s technical advisor. The tender team consisted of around 70 people and the review team had around 30 people, from different disciplines.

Were there any unexpected events during the creation of tender? If yes, which?

No, not really.

Was the resulting tender bid realistic and feasible? Why?

At the time it was made, all the parties that checked and review the bid thought that it is feasible and realistic.

What could have been improved in the tender - overall?

The way that the risk was approached in the contract could be improved, moving some risks from contractor to client. Usually those would be risks that contractor doesn't have any influence on, but still agrees to take them.

4. WOG - Client induced change:

How was the WOG document developed?

What were the techniques used in defining the tender documents?

How many people were involved? Which disciplines were involved?

Here an error was made. Usually when you have the change in the contract, you would first agree what is the change before implementing it in the project. Here the client insisted to continue working while the change was not completely identified, and Levvel eventually complied with that. The communication and cooperation in that moment with client was very good, but after a year that changed drastically.

More than 20 people were involved in creation of the WOG, from different disciplines. WOG team went into a cooperation mode with the client to try to resolve the issues. Also, different experts from the different fields, give their judgment on how long the incorporation of the change will take.

Were there any unexpected events during the creation of tender? If yes, which?

The communication with client changed after a year. We went from a really good mutual cooperation, where decisions were made together and every step we would take client would reimburse, to sending letter between parties, each from their own perspective.

How was coped with such unexpected events?

That change in communication was just accepted back in time, but now is leading to big discussions.

Was there a contingency budget and buffers to cope with unexpected events? Were these used? Was it enough?

There was none.

Was the WOG realistic and feasible ? Why ?

It was feasible until the client changed the contract team, after a year more or less. After that it wasn't realistic.

What could have been improved in the WOG - overall?

Stopping the project and finding the exact consequences of the change would be the best solution for this situation. Alternative solution could be reached if the client continued the good cooperation that was agreed on the beginning.

5. Final:

Why the project was not stopped, after identifying the errors?

That decision came from the higher management, regardless of the advice of the examinee to stop it.

What would have been the consequences of stopping the project ?

The consequences in that moment would increase the turnover and bring some bad publicity for the company. But, from this perspective that would be almost neglectable, compering to the bad reputation, increase in cost and huge delays that we are facing now.

What are the lessons learned from this project ?

The project should be stopped to consider the consequences of change, except if there is a good reason for continuing, but having in mind that bad publicity is not one of them. It is very hard to explain the complexity of the project to the client. The project as complex as this one, should never be put on so much time pressure, so more buffers and contingency budgets are needed. On this project there were some , but not even close enough.

EXPERT 4

1. Personal:

What is your profession? How many years of experience?

Before Levvel, what was the previous project, you have been working on ?

Was it a success ? In what respect?

The examinee is doing project control for around 12 years, has studied building environment and public administration. The previous project was A50 highway, and the project wasn't a success, with around 30% cost overruns and around 100% delays.

2. Project:

What was/is your position on the project ?

How would you consider this project, regarding time, money, size, difficulty ?

The examinee is not currently working on a project. His position was inside a team that was working with claims. His role was a lead planner of the Afsluitdijk. The classification of the project by him, on scale from 1 to 5, is a solid 4 in all of the categories. While still very difficult, by his opinion it isn't the most extreme project the Netherlands saw. Nevertheless, he noted that the project could also be called a program, based on its size and the number of objects it consists of, also refers to the Afsluitdijk as an icon of the Netherlands.

3. Tender:

The examinee was not working on the project in the time tender was made.

4. WOG - Client induced change:

How was the WOG document developed?

What were the techniques used in defining the tender documents?

How many people were involved? Which disciplines were involved?

The examinee, and his team took one year and a half to create the new plan. The biggest problem for them was that the scope of the WOG was not defined fully. This led to RWS not accepting neither the plan they made or the scope they were involving in the plan. Another problem was to filter what was the mistake of the client and what was the mistake of LevveL. A lot of time and energy was spent in the countless meetings and discussions with the client to sort this out and make it clear to both sides who is the owner of the problem. The team he was working in was made of 7 people from different disciplines, but also another 30 people gave their input for making of the WOG. Those other people would usually be project manager and project planners, from different departments, that would give their assumptions on the impact of scope change to their part of the project.

Were there any unexpected events during the creation of tender? If yes, which?

New problems were arising every now and then, making it impossible to focus either on the WOG or the daily operational processes of project.

How was coped with such unexpected events?

During the first year, the coping mechanism for newly raised problems was to, together with the team, solve all of them. After a year, his team had a meeting where they established that with this pace of work, they will never finish their part of job, which is completing the WOG. This decision was followed with a change of higher managers in LevveL, that gave more room to the team to focus on the WOG.

Was there a contingency budget and buffers to cope with unexpected events? Were these used? Was it enough?

The WOG was planned to be done in half a year period, but now after two years it still isn't complete. The contingency budget and the time buffers were not really included.

Was the WOG realistic and feasible ? Why ?

Yes, the plan was realistic, the failure resulted from the constant changes in scope.

What could have been improved in the WOG - overall?

The WOG could be realized as a part with big impact for the Afsluitdijk, probably big enough to stop the project for a couple of months, at least until the scope is frozen and clear to everyone. Also, guidance from both the company and the client should have been more concise.

5. Final:

Why the project was not stopped, after identifying the errors?

The project was not stopped because the higher management never truly understood the consequences that the scope change will have. It could be said that the effects of the disruptions were highly underestimated. Also, DBMF contract is not the easiest type of contract to stop.

What would have been the consequences of stopping the project ?

The pressure that was put on the team to parallelly execute both the WOG and the daily operational process of the project would be far less, resulting in less delays and cost overruns, but would increase the political pressure and reputation loss. Also, it would definitely lead to some not so pleasant discussion with the RWS.

What are the lessons learned from this project ?

The frozen and clear scope is the most important part of the project this big. Never should the uncertainties take over any project, especially a one this big and important. Also, the communication between the client and the contractor has to be clearer, especially in the beginning of the disturbance. Finally, when the WOG is this big, as in the case of Afsluitdijk, the project should be stopped to avoid working in parallel with daily operational processes.

Appendix C - All formulas

Table 11. All Formulas used in the Model

Accumulation New Staff	Co Hiring Staff; Initial:0
Accumulation Planned Staff	Co Planned Hiring; Initial:0
Accumulation Scope Change	Co Scope Change Initial:0
Approval	Work Done/Months for Approval
Approval Influence	([(0,0)-(100,0.5)],(0,0),(20,0.05),(40,0.1),(60,0.15),(80,0.2),(100,0.25))
Co Planned Hiring	Planned Hiring
Co Scope Change	Scope Change
Effective Productivity	Planned Productivity by One Staff*Productivity
Error	IF THEN ELSE(Schedule Pressure>0.5:AND:Overtime Hours>40:AND:Office Congestion>0, Error Input, 0)
First Order Approval	First Order WD
First Order Progress	First Order WRD/(First Order WD +First Order WRD + First Order WTBD)
First Order Scope Change	Scope Change
First Order WD	First Order WR-First Order Approval; Initial:0
First Order WR	MIN(First Order WTBD, Planned Productivity by One Staff*Accumulation Planned Staff)
First Order WRD	First Order Approval; Initial:0

First Order WTBD	First Order Scope Change-First Order WR; Initial:0
Hiring Staff	IF THEN ELSE(ZIDZ(Accumulation New Staff, Accumulation Planned Staff)<=Max New Staff, IF THEN ELSE(Perceived Progress<0.9*Planned Progress, New Staff Hired per month, 0), 0)
Morale Influence	([(0,0)-(1,1)],(0,0),(0.25,0.425),(0.5,0.525),(0.75,0.75),(1,1))
New Staff	Hiring Staff-Training of Staff; Initial:0
Obsolescence 1	MIN(Work Done, Scope Change*(1-Obsolence Factor))
obsolescence 2	MIN(Work Really Done, Scope Change*(Obsolescence Factor))
Office Congestion	ZIDZ(Accumulation New Staff, Accumulation Planned Staff +Accumulation New Staff)
Office Congestion Influence	([(0,0)-(1,0.2)],(0,0),(0.5,0.1),(1,0.2))
Old Staff	Training of Staff + Old Staff Hiring; Initial:0
Old Staff Hiring	Planned Hiring
Overtime Hours	IF THEN ELSE(Perceived Progress<0.9*Planned Progress, 40+Overtime Hours Input, 40)
Overtime Influence	([(30,0)-(65,1.5)],(35,1.05),(40,1),(45,0.95),(50,0.9),(55,0.85),(60,0.8),(65,0.75))
Perceived Progress	Work Really Done/(Work Done +Work to be Done + Work Really Done)
Planned Approval	Planned Work Done
Planned Dismiss	IF THEN ELSE((Time>8:AND:Time<9):OR:(Time>21:AND:Time<22), 6, 0)
Planned Hiring	IF THEN ELSE((Time>0:AND:Time<1):OR:(Time>2:AND:Time<3), 6, 0)
Planned Progress	Planned Work Really Done/(Planned Work Really Done + Planned Work to be Done + Planned Work Done)

Planned Staff	Planned Hiring-Planned Dismiss; Initial:0
Planned Work Done	Planned Working Rate-Planned Approval; Initial:0
Planned Work Really Done	Planned Approval; Initial:0
Planned Work to be Done	-Planned Working Rate; Initial:0
Planned Working Rate	MIN(Planned Productivity by One Staff*Planned Staff, Planned Work to be Done)
Productivity	Overtime Influence*Schedule Pressure Influence*Morale Influence*(1-Office Congestion Influence)
Rework Cycles	Repeat Cycle; Initial:0
Rework due to Errors	IF THEN ELSE(Perceived Progress<0.99, Error*Working Rate, 0)
Rework Influence	([(0,0)-(6,1.1)],(0,1),(1,1),(2,0.9),(3,0.8),(4,0.65),(5,0.55),(6,0.5))
Schedule Pressure	IF THEN ELSE(Perceived Progress<0.9*Planned Progress, Schedule Pressure Input, 0)
Schedule Pressure Influence	([(0,0)-(1,1)],(0,1),(0.1,0.85),(0.2,0.9),(0.3,0.95),(0.4,1),(0.5,0.9),(0.6,0.8),(0.7,0.7),(0.8,0.65), (0.9,0.6),(1,0.55))
Scope Change Influence	([(0,0)-(100,2)],(0,1),(10,1),(20,1),(30,0.9),(40,0.8),(50,0.7),(60,0.6),(70,0.5),(80,0.5), (90,0.5), (100,0.5))
Training of Staff	New Staff/Months of Training
Work Done	Working Rate-Approval-Obsolescence 1-Rework due to Errors; Initial:0
Work Really Done	Approval-Obsolescence2; Initial:0
Work to be Done	Rework due to Errors +Scope Change-Working Rate; Initial:100
Working Rate	MIN(Work to be Done, Old Staff*(Overtime Hours/40)*Effective Productivity)

Appendix E- Yassmin- Interviews Protocol

Introduction

I'd like to thank you for willing to participate in this interview as part of my master thesis. First, I will introduce myself, the research, and the objective of today's interview.

Introduction researcher & study. My name is Yassmin Hassan, and I am a master student in construction management Engineering at TU Delft. At the moment I am conducting my thesis. As part of my thesis, I am pursuing an internship at LevveL. In my thesis, I focus on analyzing and quantifying the impact of scope change on the Afsluitdijk project through developing a system dynamics model. Currently, I am focusing on the impact of uncertainties/risk resulting from the scope change on team morale.

Goal interview: The goal of this interview is to understand the impact of design uncertainties on the staff morale. Also, to compare how the uncertainties/risk management and morale differed before and after the scope change.

Confidentiality: This interview and all answers given to any questions will remain confidential. All personally identifiable information will be removed before processing and presenting the data. However, to support the notes and write the script, I would like to record the interview. Is that okay with you?

Questions tackled in the interviews

Background of the interviewee

1. How long have you been working on the Afsluitdijk project?
2. Can you briefly describe your background experience?

Uncertainty/risk definition and experience in the project

How do you define uncertainty/risk?
Based on your definition have you experienced design uncertainty/risks during the scope change?
What were the causes and effects of this design uncertainty/risk?
What are the design uncertainties/risks that you faced during the scope change process?

Impact of design uncertainty/risk management on morale

How did design uncertainty/risk management impact your motivation? Yes, how was that visible? no, why not?
How do you think design uncertainty/risk management impacted the team?
Do you think that design uncertainty/risk management impacted the team morale?

Action taken to overcome the loss of morale

Have you done or the team did to overcome the impact of uncertainty/ risk management problems? Did that work? What obstacles did you face to apply that or even after applying?
What could have been done to reduce design uncertainty/risk management problems or deal with it better?

Appendix F- Yassmin- Interview Answers

Based on the questions of the interviews included in Appendix E, the author summarized all the findings of the seven interviews using Atlas.ti. A network tool was used to establish connections of the quotations. In this Chapter the author will focus on the main results of the interviews. All the interview's findings are summarized and added in Appendix F.

Design uncertainty interviews networks

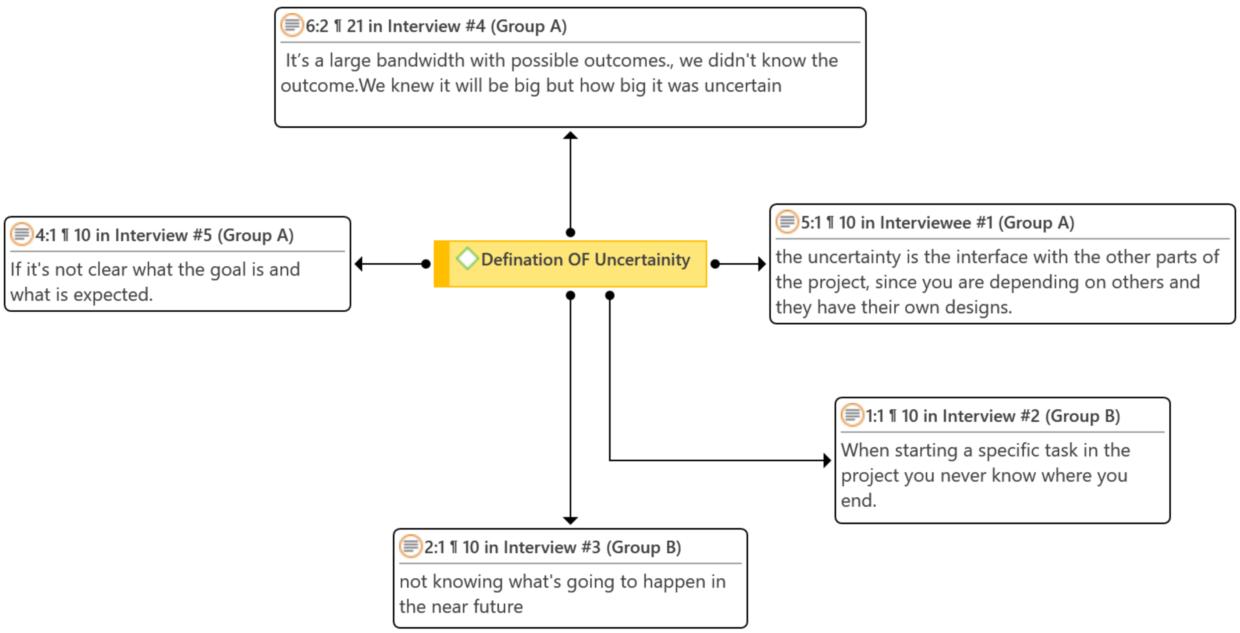

Figure 44. Definition of Uncertainty

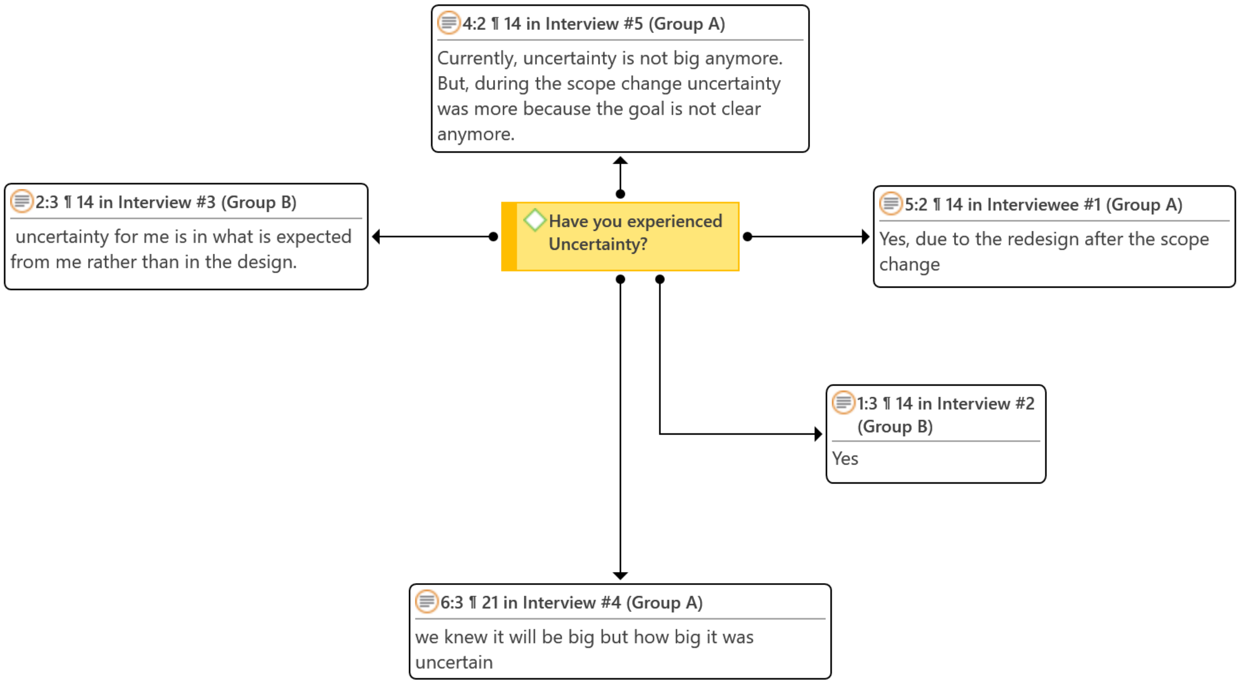

Figure 45. Have you experienced Design uncertainty

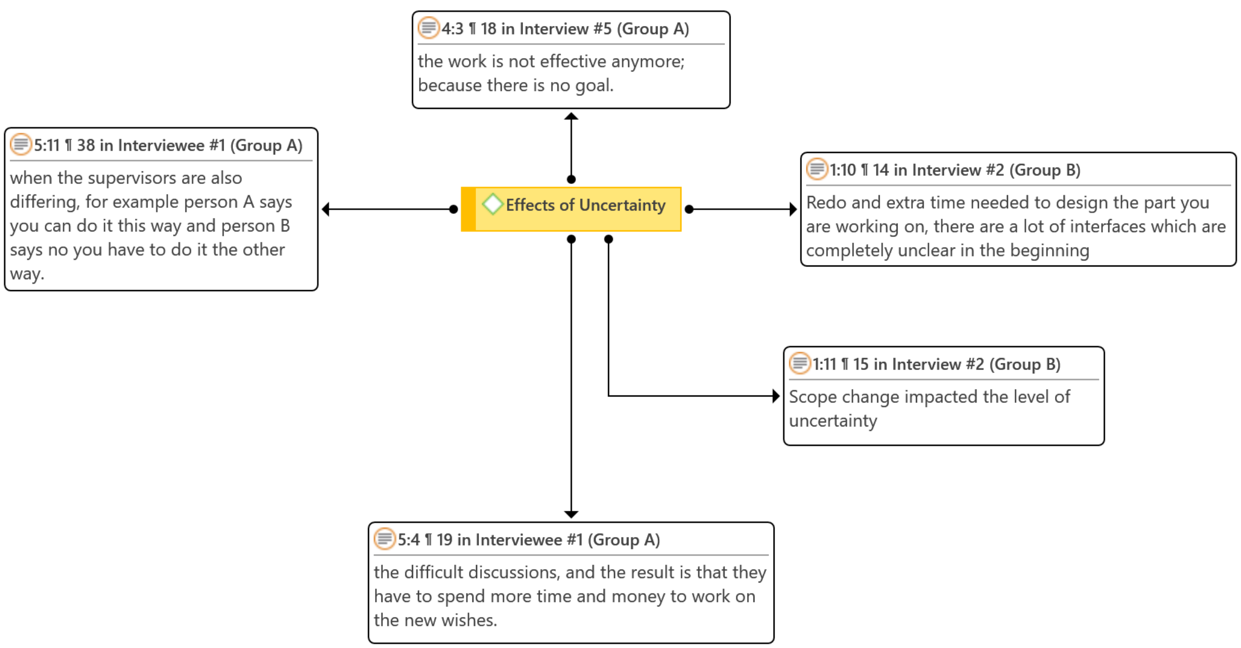

Figure 46. Effects of Design uncertainty

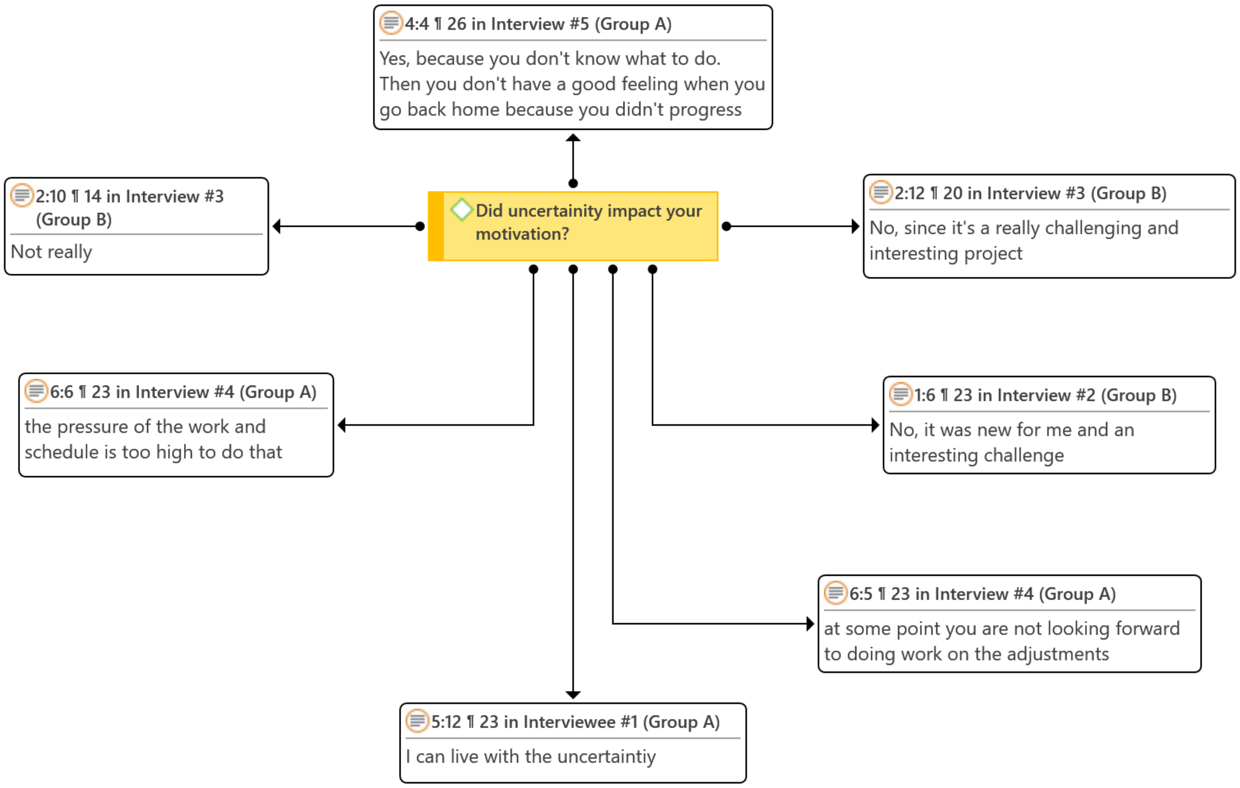

Figure 47. Did design uncertainty Impact your motivation?

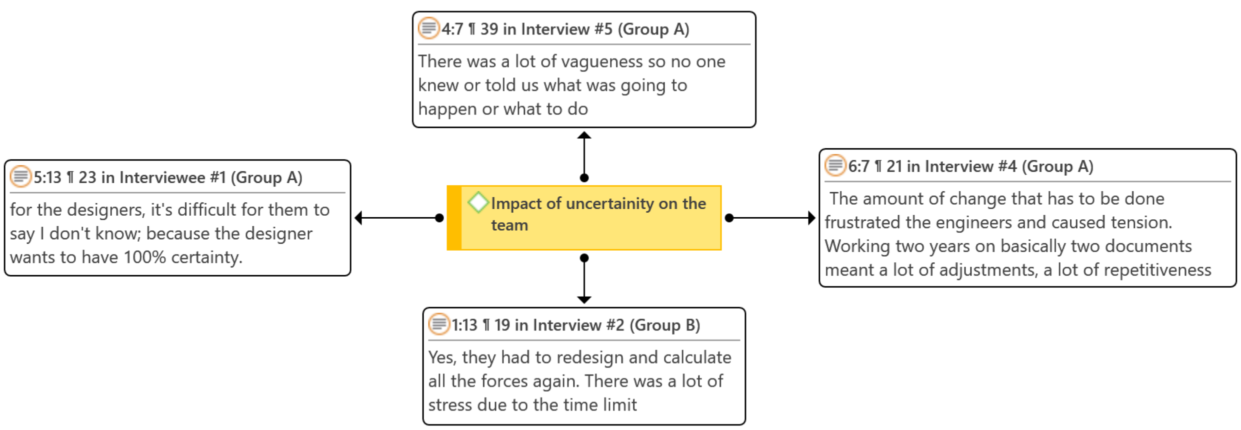

Figure 48. Impact of design uncertainty on the team

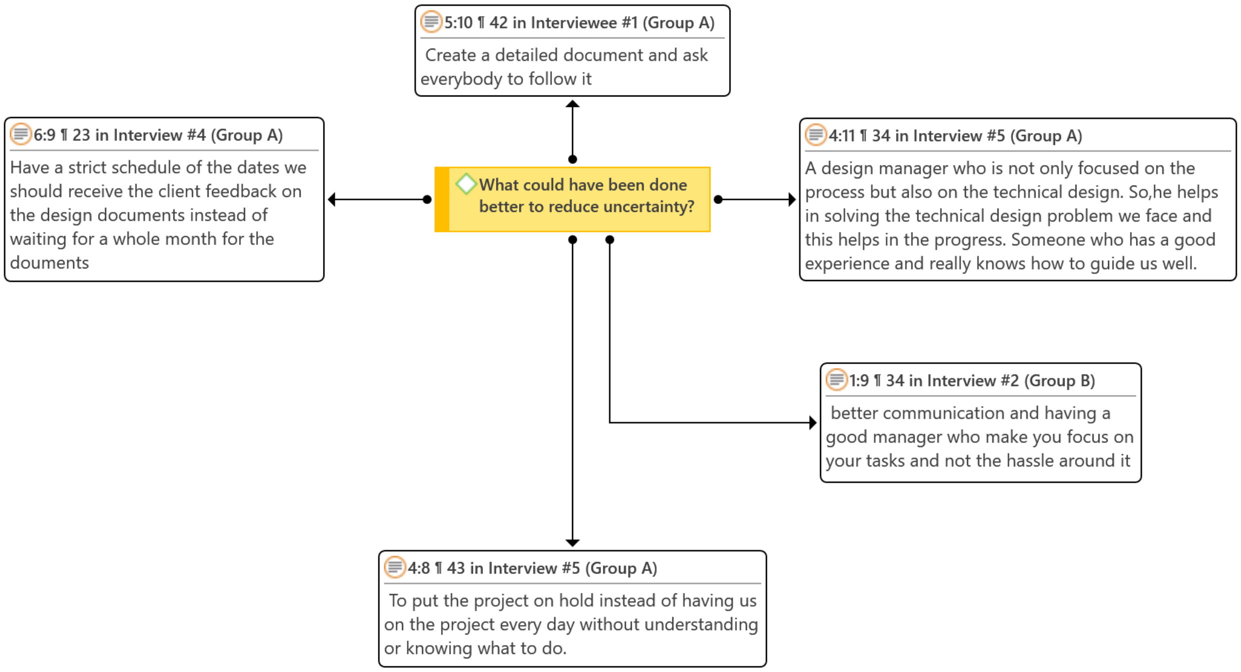

Figure 49. What could have been done better to reduce design uncertainty?

Risks interviews networks

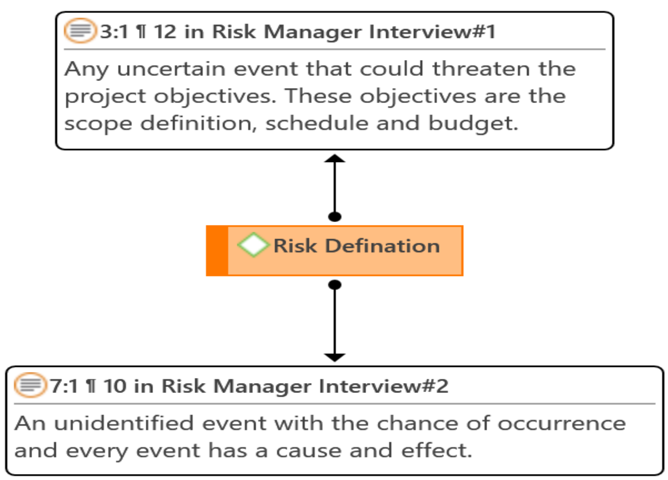

Figure 50. Risk Definition

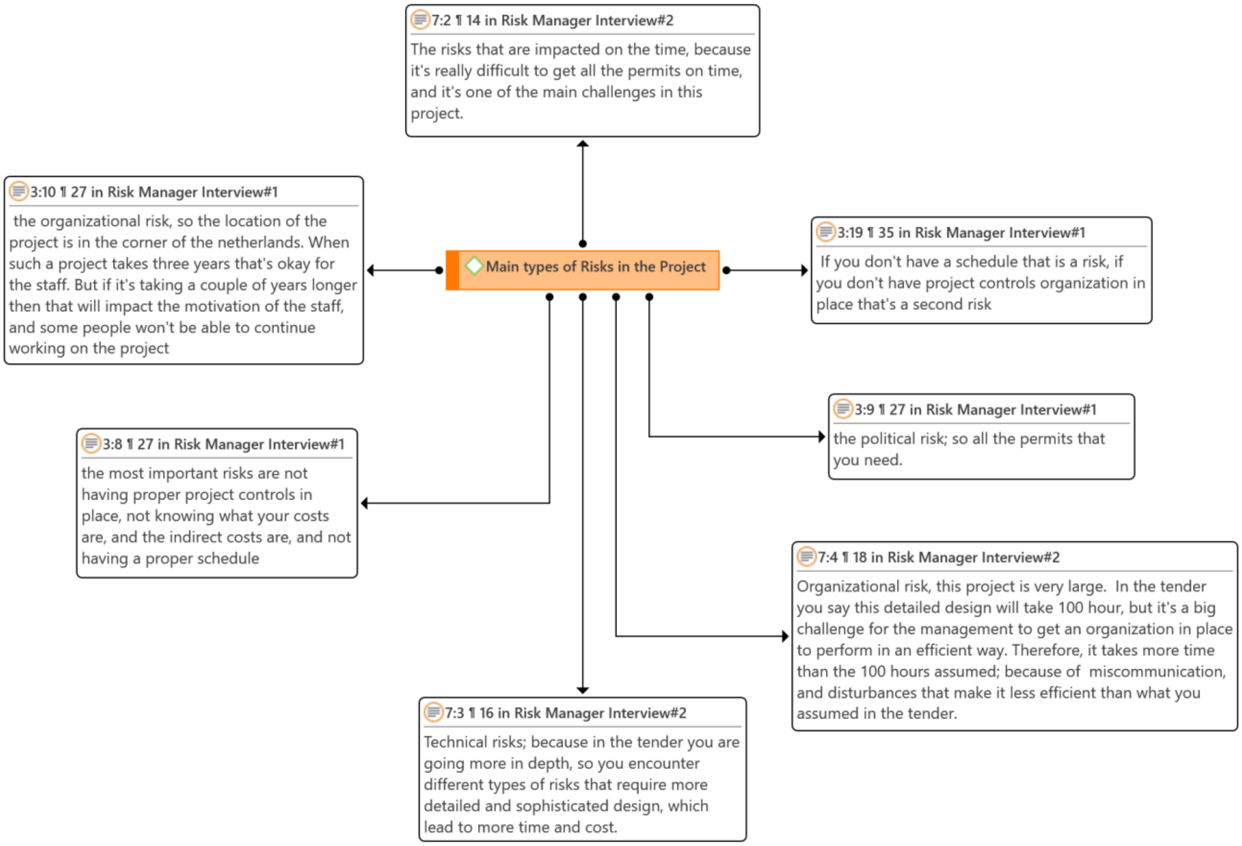

Figure 51. Main types of risks in the project

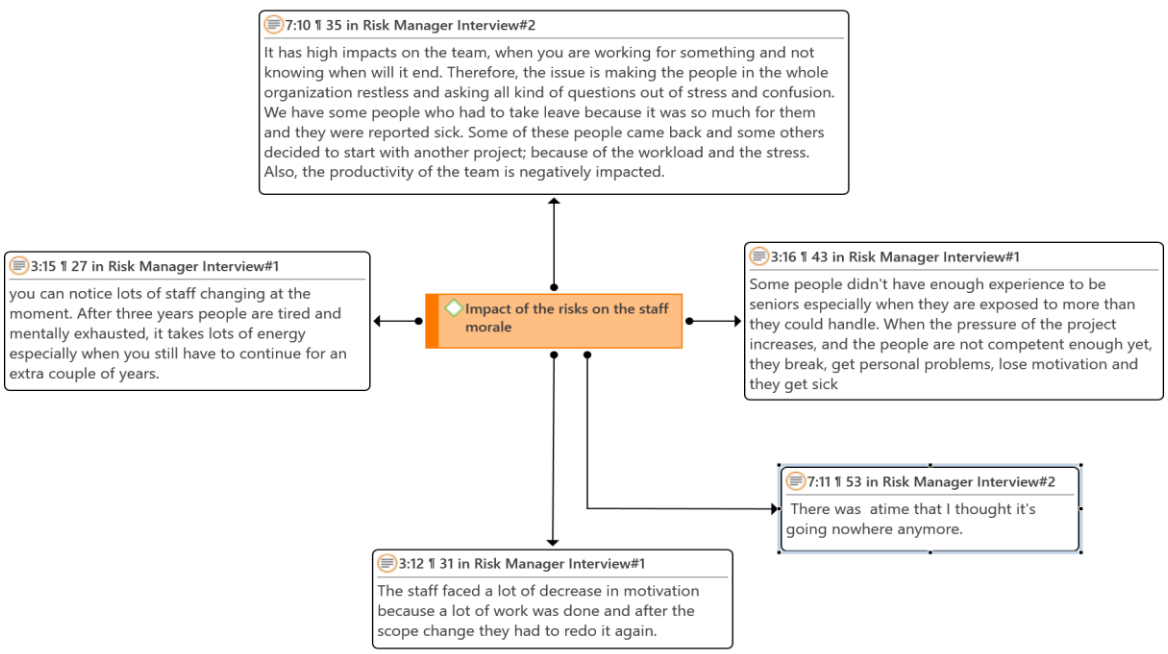

Figure 52. Impact of risk management on the staff morale

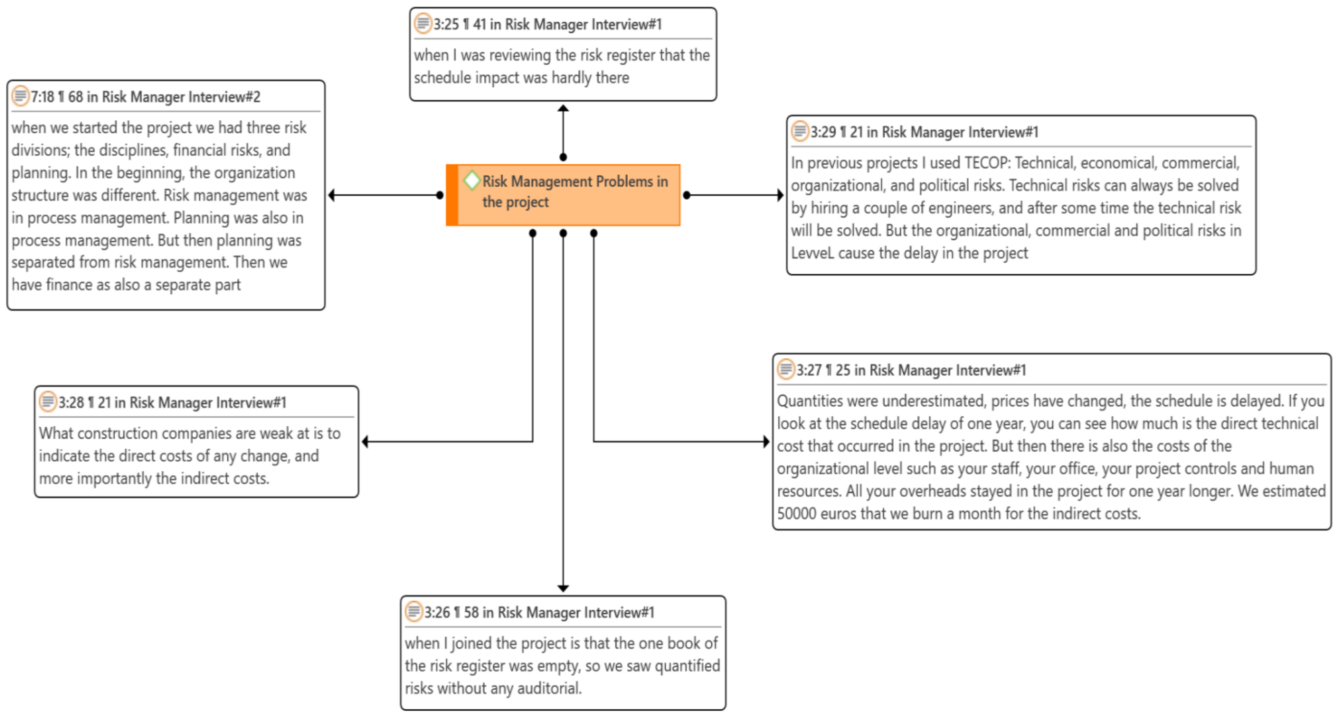

Figure 53. Risk management problems in the project

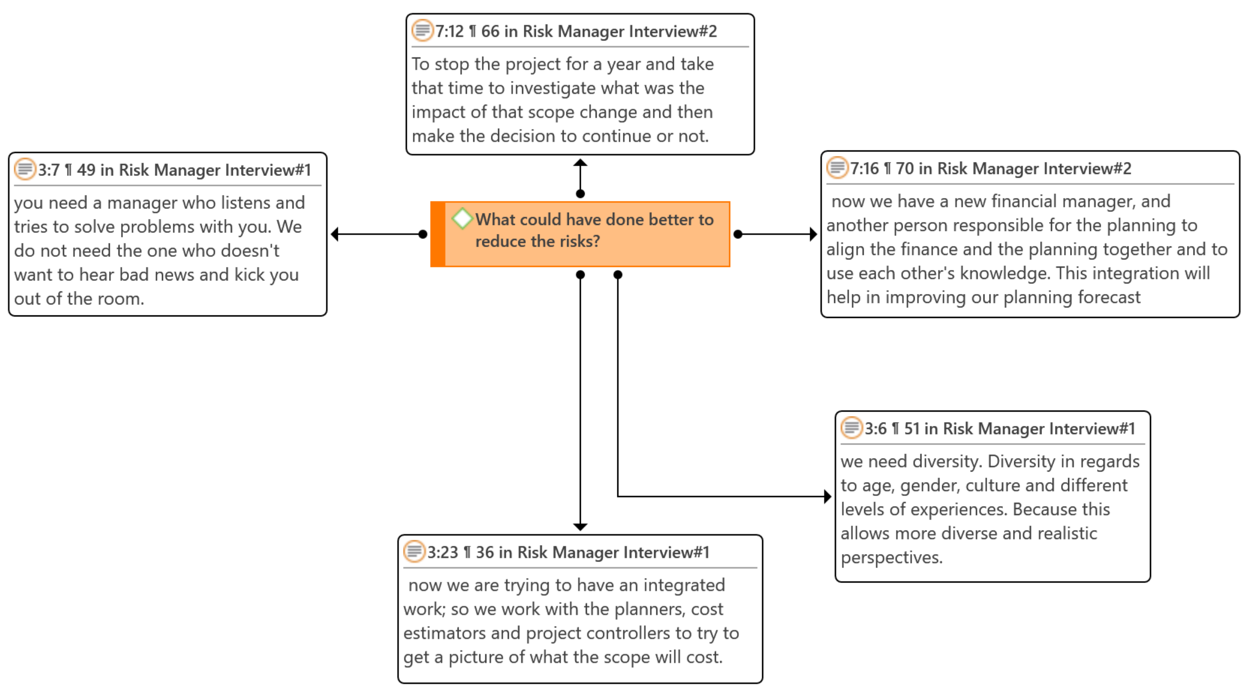

Figure 54. What could have been done better to reduce the risk management problem?